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PAPER

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A RETROSPECTIVE STUDY OF RADON DAUGHTER CONCENTRATIONS IN THE WORKPLACE IN THE FLUORSPAR MINES OF ST. LAWRENCE, NFLD.

by

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ABSTRACT

Fluorspar mining began in St. Lawrence, Newfoundland in the early thirties. In the early years the existing economic and social conditions resulted in poor health and safety practices in the mines. A high incidence of many types of pulmonary diseases, including lung cancer, among the miners was investigated by the Department of National Health and Welfare, and by 1960 radiation in the mines was recognized as the major cause.

The original epidemiological study used radon daughter exposure estimates determined from a limited number of radon daughter measurements in one of the mines. Insufficient experience existed at that time to allow a proper technical assessment of the mines and to modify the estimated radon daughter concentrations accordingly. A review of the environmental conditions in the early years of mining and a revision of the estimates of radon daughter concentrations in those mines is presented. Environmental working conditions were determined based on a review of maps, inspectors' reports, Commission hearings, recollections of former workers and of the authors. Comparison to the conditions in the mines in later years, when radiation samples were taken more frequently, allowed estimations of the probable radon daughter concentrations that would have existed in the mines earlier. Ranges of estimated average concentrations were made by mines for each year and wherever possible for broad types of job classes. Rather than attempting to propose single numbers for radon daughter concentrations, which in turn might have implied an accuracy that did not exist, ranges of average radon daughter concentrations were estimated.

RESUMÉ

L'extraction minière de spath fluor a commencé à St. Lawrence (Terre-Neuve), au début des années 1930. Dans les premières années, les conditions économiques et sociales existantes ont donné lieu à des mesures insuffisantes d'hygiène et de sûreté dans les mines. Le ministère de la Santé et du Bien-être social a mené une enquête sur l'incidence élevée de plusieurs types de maladies pulmonaires, y compris le cancer du poumon, chez les mineurs et, dès 1960, le rayonnement dans les mines était identifié comme en étant la cause principale.

La première étude épidémiologique avait recours à des calculs estimatifs de l'exposition aux produits de filiation du radon, établis à partir d'un nombre limité de mesures des produits de filiation du radon dans une des mines. Étant donné le manque d'expérience, à cette époque, il était impossible d'effectuer une évaluation technique appropriée des mines et de modifier les concentrations estimées de produits de filiation du radon en conséquence. Le présent rapport fait état des conditions environnementales qui existaient dans les premières années de l'extraction minière et fournit les calculs estimatifs modifiés de concentrations des produits de filiation du radon dans les mines en question. Une révision des cartes, des rapports d'inspecteurs, des comptes rendus des audiences de la Commission, des commentaires d'anciens travailleurs et des auteurs a permis d'identifier les conditions qui prévalaient alors dans le milieu de travail. Le parallèle avec les conditions des années plus récentes dans les mines où l'on effectuait de plus fréquents échantillonnages de rayonnements, a permis d'évaluer les concentrations probables de produits de filiation du radon qui ont pu exister au départ dans les mines. On a établi des gammes de concentrations moyennes estimées par mines, pour chaque année, et dans tous les cas possibles, pour des types généraux de classifications de postes. Plutôt que de tenter de proposer des données uniques pour les concentrations de produits de filiation du radon, qui auraient pu par ailleurs laisser croire à une précision inexistante dans les faits, des calculs estimatifs ont permis d'établir des gammes de concentrations des produits de filiation du radon.

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1. INTRODUCTION

Fluorspar mining was carried out in St. Lawrence Newfoundland from the early thirties until 1978 when the last of the many mines closed. The existing economic and social conditions, and the remote location resulted in poor health and safety practices in the early years in the mines. The high incidence of many types of pulmonary diseases among the miners, including lung cancer, was investigated by the Department of National Health and Welfare, and by 1960 airborne radiation in the mines was recognized as the probable cause. By 1962, 29 miners had died of lung cancer[1]. This number had risen to 78 by 1977[2] and as of July 1981, 105 cases were identified[3].

The Department of National Health and Welfare and the Atomic Energy Control Board are in a process of updating and re-evaluating the original epidemiological study. The original study used results from a limited number of radon daughter measurements obtained at Director Mine only to calculate radon daughter exposures for the entire study population which worked in several mines in the area. Unfortunately, the knowledge of the behaviour of radon daughters in mine atmospheres was limited. In spite of very low accuracy in the assigned concentrations, single numbers rather than ranges were used. This may imply a degree of accuracy which was not justified.

Based on the experience at the mines of Newfoundland Fluorspar Limited (Newfluor) and more recent experience in other mines where radon daughters are present there are reasons to believe that the concentrations of radon daughters and, therefore, the calculated exposures of the study population have been underestimated[4].

In this paper, the individual mines in the area were assessed on the basis of existing mine maps and known mining and ventilation practices for each year of their operation. The reports of mine inspectors who carried out periodical inspections, testimony at hearings, and the recollection of individuals who worked in the mines were used to estimate working environment conditions as they were likely to have existed. These were then compared to the conditions which existed in the Director and Tarefare mines in later years when extensive radon daughter monitoring was done. Based on these comparisons, ranges of average radon daughter concentrations are estimated for each mine by year and, where possible, for types of jobs.

Mining of fluorspar in St. Lawrence began in 1933 by the St. Lawrence Corporation. Fluorspar was initially mined by open cut methods and later, underground, by shrinkage or cut and fill (Director and Tarefare) methods. As mining started in the middle of the Depression, early work was done with secondhand antiquated equipment. Health and safety conditions in general and working environment conditions (dust and water), in particular, were poor[5,6,7]. It was not until 1941 that the St. Lawrence Workers Protective Union was formed and a series of strikes ensued resulting in union recognition, higher wages, and improved working conditions. The improved working conditions included the gradual abandonment of the use of dry drilling underground, the introduction of mucking machines and electric trammers, and most significantly the introduction of two eight-hour shifts per day so that the mine could be cleared of gases and dust during the four hours between the staggered shifts. There was practically no forced ventilation at any of the mines up to 1960. The only source of ventilation was the natural draft.

Inspectors were brought in from Ontario in most years by the various Newfoundland governments to inspect the mines. There were no mining regulations until 1951. The inspectors relied on persuasion only to achieve gradual improvements over the years as documented in their reports[8].

By the end of 1955 several deaths caused by lung cancer have occurred among St. Lawrence miners. At that time, the workers and their families, the Union and the Companies, began to suspect that there was some connection between the mining environment and the incidence of lung cancer. The Provincial Department of Health was also aware of the increasing number of chest illnesses among the miners and asked the Department of National Health and Welfare in Ottawa to make an investigation at the mines. In 1957, officials of the Department of National Health and Welfare made a study of dust conditions in the mines and found nothing to tie them in with the increasing evidence of lung cancer incidence[9].

There was no evidence of radiation in the mines at this time. Measurements of gamma radiation were made for other purposes in 1952 or 1953. These measurements gave no indication of radiation[10]. Late in 1959, officials of the Department of National Health and Welfare made a radon daughter survey in the mines and discovered that radiation was present[11]. However by 1958, the Corporation's mines had ceased production and at the time of the surveys in 1959, all the mines were already flooded. The surveys were executed at the Director Mine of Newfoundland Fluorspar Limited, subsidiary of the Aluminum Company of Canada Limited. The experience of this large industrial company was evident in the better working conditions in its mines and was recognized by the Royal Commission Respecting Radiation, Compensation and Safety at the Fluorspar Mines[12].

2. MINING

Fluorspar occurs in the St. Lawrence area in the form of veins filling faults and fissures in granite. There are two major vein systems:

a) East-West - narrower, high purity fluorite.

b) North-South - wide, lower purity fluorite.

Generally, a significant flow of water was associated with the veins. This water was later identified as the transport medium for radon into the mines. Concentrations of up to 476 Bq/L (12850 pCi/L) in the mine water were measured[13]. The mining and ventilation practices of individual mines were extensively reviewed to estimate the work environment conditions. The main features of the individual mines are summarized below.

2.1 Black Duck

The Black Duck vein was almost vertical with an average width of 1.2 meters. The vein was mined by open cut to a depth of approximately 25 meters.

Underground mining extended to a depth of about 75 metres, and was carried out for about 220 metres to the West and 25 metres to the East from the shaft. Stopes were mined without any breakthrough to the surface and, therefore, ventilation was only by compressed air from drills. Drilling was dry. Up to 19 L/s of water were pumped from the mine. Shrinkage and underhand benching was used to mine the fluorspar. The mine closed in 1941.

2.2 Blue Beach

Blue Beach vein is a North-South vein inclined from 75° to almost vertical. The width in the mined areas was 1.5-8.0 metres with generally bad ground conditions. Mining was done by shrinkage stoping. Breakthrough to the higher level or to the surface was established only when the pillar was reached. Due to bad ground conditions, some backfill was used to fill the stopes after the ore was removed.

The mine was first opened by No. 3 inclined shaft to an eventual depth of about 70 metres. Mining activities extended approximately 360 metres to the North and 600 metres to the South from the shaft. There were three levels at 18, 39, and 69 metres. During the development of the 39 metre level, a ventilation raise was driven to the surface about 460 metres South of No. 3 shaft. The 69 metre level was opened in 1951 when No. 3 shaft was extended to that depth, and a new No. 2 shaft was sunk about 455 metres South of No. 3 shaft. Approximately 28 L/s of water were pumped from the mine. The mine closed down in 1957.

2.3 Haypook

Haypook is an East-West vein, almost vertical. The vein was originally opened in 1953 from the 39 metre level of Blue Beach mine. Lateral development and mining proceeded by shrinkage stoping to the East and West and a raise to the surface was driven. Activities extended about 120 metres West and 320 metres to the East.

The 69 metre level was developed again by a crosscut from Blue Beach Mine. A raise was driven to connect with the 39 metre level. The raise was later enlarged into a shaft. Mining on this level extended about 120 metres West and 90 metres East. The mine closed and flooded in June, 1957 and re-opened March 1960 for one year. The shaft was deepened and a 100 metre level was established, but no mining was done. The average width of the Haypook vein was about 1.8 metres. About 6.3 L/s of water were pumped from the mine.

2.4 Hares Ears

Hares Ears is a North-South vein almost vertical, and for this type of vein an exceptionally high grade. It has been mined at two different times to the depth of 62 metres with levels at 20, 52,and 82 metres for approximately 170 metres to the North and 60 metres to the South from the shaft. Mining was done by shrinkage stoping with about 9.5 L/s of water pumped from the mine. The width of the mined vein was 1.2-3.6 metres.

2.5 Iron Springs

Iron Springs is an East-West vein with a dip of 70° and mined width of 0.75-1.5 metres, with occasional width of 3.6 metres. The mine had only one shaft and mining progressed by shrinkage stoping on 18, 30, 54, 72, 102, 135, 168, 201, 237, and 267 metre levels for about 500 metres East and 500 metres West from the shaft. Although raises were sometimes driven to the next level above before stoping commenced, due to the significant depth of workings and length of lateral access ways, ventilation at this mine was likely the worst of all the mines in the area. About 60-70 L/s of water were pumped from the mine.

2.6 Red Head

Red Head is an East-West vein. Limited mining was done on 15 and 40 metre levels. Stoping was done about 100 metres to the East. Ventilation raises were driven in the stopes. Shrinkage method of mining was used. The mine was dry.

2.7 Director

Director is a North South vein. Before 1960, the mining extended to a depth of 165 metres with levels at 25, 45, 75, 120, and 165 metres. The lateral extent of mining was over 1,000 metres with three shafts to the surface. Some shrinkage stoping was done in the mine, but 95% of production came from cut and fill mining. As a result, ventilation was much better than at other mines as raises for fill had to be driven before stoping commenced. The mined width of the vein varied from 1.5 to over 10.0 metres. The mine was very wet with about 160 L/s of water pumped. Mechanical ventilation was providing 4.72 m^3/s of air on the 75 metre level. Development headings exceeding 150 metres in length had mechanical auxiliary ventilation. Otherwise, natural ventilation was used until 1960.

2.8 Tarefare & Blowout

Tarefare and Blowout are two parallel North-South veins. Very little mining was done prior to 1960 on the 25 metre levels from the Tarefare shaft.

There are numerous other veins in the St. Lawrence area, and most of them were explored at one time or another. However, major mining activity occurred only on those listed above.

The Director and Tarefare mines were operated by the Newfoundland Fluorspar Limited and had much better ventilation and working environment conditions than the other mines operated by the St. Lawrence Corporation.

3. WATER AS THE SOURCE OF RADON IN THE MINES

Radon daughters were first measured in the mines in late 1959 and subsequently identified as the cause of the high incidence of lung cancer[14, 15, 16]. Eventually the mine water was identified as the carrier of radon into the mines. Samples of water analysed by Atomic Energy of Canada Ltd.[17] yielded the following concentrations of radon 222:

Director mine water	476 Bq/L (12850 pCi/L),
Hares Ears shaft water	445 Bq/L (12030 pCi/L),
St. Lawrence town water supply (well)	532 Bq/L (14370 pCi/L),
and	341 Bq/L (9200 pCi/L).

Although water samples from other mines were not analyzed for radon content, the above data supports the assumption that mine water in the other mines would also have had a high content of radon.

4. WORKING CONDITIONS FOR THE PERIOD 1933-60

Various documents contain personal accounts of the working conditions in the mines of the area prior to 1960[18,19,20,21]. Of particular interest were the conditions in the two large mines Director, and Iron Springs mines. Most of the complaints about working conditions originated from the Iron Springs Mine.[22] A comparison was made between the known conditions of the Director Mine in 1959-60 and later and the assumed working conditions of the other mines. Based on this comparison estimates of radon daughter concentrations were made for the mines not monitored.

Some improvement in the working environment resulted from the introduction of the two shift per day operation, (at the end of World War II), with four hours between shifts. Compressed air was used between shifts to provide some ventilation. In spite of these measures, incidences of gassing were very frequent. Instances of flames going out for lack of oxygen were also common, indicating that ventilation was in many cases practically non-existent. The reports of Mine Inspectors and recollection of workers generally supported the above conclusion. It is evident that only very small amounts of air was provided to clear smoke and dust and to reduce the radon daughter concentrations. The air passed through many workplaces gradually accumulating radon and radon daughters. As the mines had no mechanical ventilation, the air movement was due to changes in air density resulting from differences in the temperature of the air inside and outside the mine (natural ventilation). Because of the cold air temperature in the winter, freezing of water pipes and equipment occurred and airflow had to be restricted. In the summer, the cool, damp air underground would be heavier than outside air and the air flows through the mine were therefore greatly reduced. As a result, the volume of natural air flows all year were not large.

5. WORKPLACE CONDITIONS AND RADON DAUGHTER CONCENTRATIONS

The survey data from the 1960 reports of J.P. Windish and A.D. Little were analyzed and used as the base for the estimates of radon daughter concentrations up to 1960. It is assumed that the samples were representative of specific environmental conditions of the locations sampled. These conditions could then be related to other mines so that an estimate of radon daughter concentrations could be made. As water was identified as the source of radon influx into the mine atmosphere, it is important to determine the amount of mine water influx.

5.1 Very Wet Dead End Headings

5.1.1 215 Drift Domestic Water Reservoir

Samples were taken in a long dead end drift dammed to retain water for domestic use. At 48 metres past the dam a match would not light indicating stagnant air conditions and oxygen deficiency. The measured concentrations were[23]:

Location	Radon Daughter Concentrations (in WL)	Radon 222 (Bq/L)
215 drift at dam	11.0	55.6 (1510 pCi/L)
	8.9	
	9.8	
215 drift at 30 m behind the dam	84.4	407.4 (11000 pCi/L)
215 drift at 54 m behind the dam	---	492.6 (13300 pCi/L)

Unfortunately, it was not possible to obtain a radon daughter sample at 54 metres. The sample locations are shown in Figure 1.

The high concentrations, shown in Figure 2 are caused by the large water surface in the drift and indicate a significant radon daughter buildup. The final equilibrium value was estimated to be 130 WL.

5.1.2 165 Level Development Headings

At the end of 1959 the main shaft at Director Mine had been sunk to the 165 metre level. Drifts had been driven 300 metres South and 390 metres North. No production areas were developed but two raises were driven to the previous level where production was in progress, one 27 metres North and the other 170 metres South of the shaft. This was the usual method of development for the mine because of the heavy flows of water that came into the lowest levels. To minimize pumping cost, lower levels were not developed much in advance of production. As a result, there was little possibility to utilize advance development for improved ventilation. Driving of long dead end headings as levels were developed was common. As a result development miners usually worked in long wet headings with little or no ventilation other than from compressed air. Therefore the sample results from the 165 level are very important.

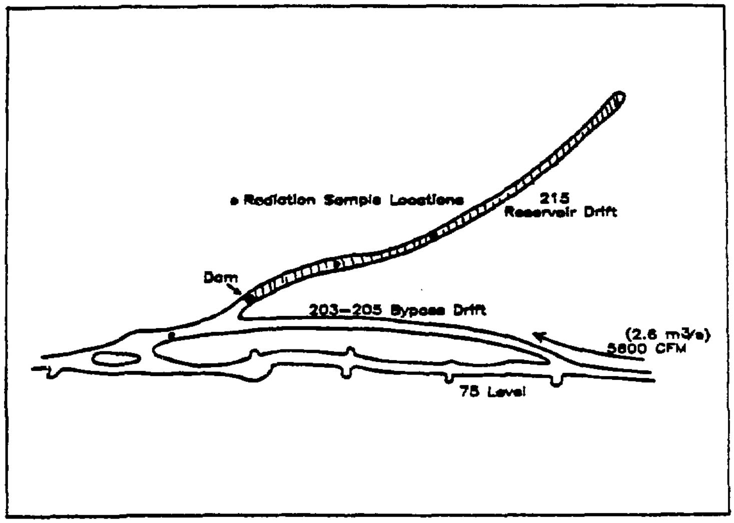


FIGURE 1. A plan view of a portion of the 75 Level DIRECTOR MINE showing the domestic water reservoir drift. This drift is an extreme case of a very wet dead end heading and was measured in 1959 up to 492 Bq/L Radon 222 (13,300 pCi/L).

FIGURE 2: Radon and Radon Daughter samples from the 215 Reservoir Drift DIRECTOR MINE.

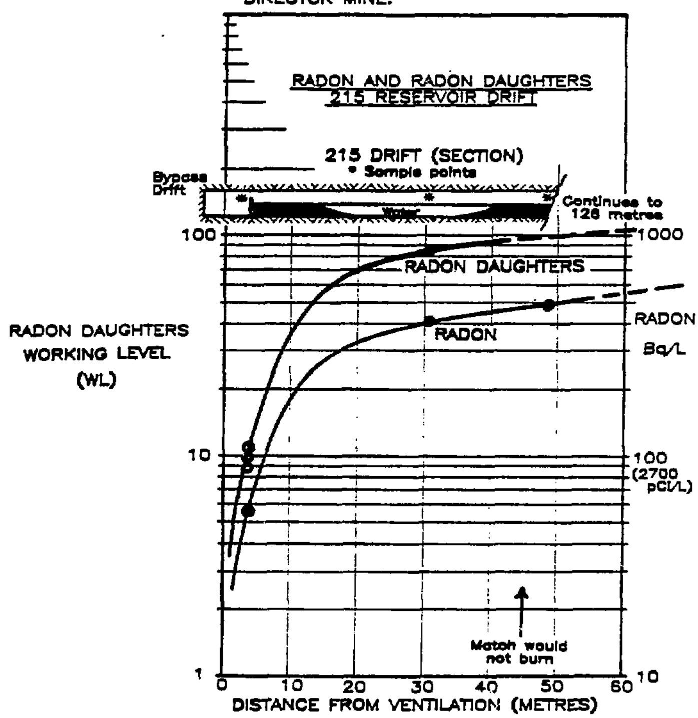
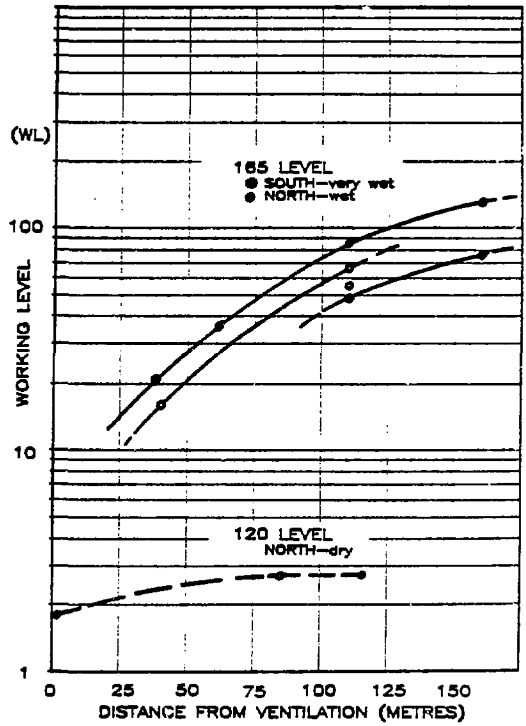


Figure 3 shows the radon daughter concentrations for both the North and South drifts (when not ventilated) as a function of distance from the last point through ventilation (ie, the shaft in the South and the access raise in the North)

Although the North drift is significantly dryer than the South drift, when no air movement existed, the radon daughter concentrations were similar. The consistent difference between the results of Windish and Little in the South drift cannot be explained. One possible explanation might be the difference in the calibration of equipment in the high range as both Windish and Little observed oxygen deficiency at the same location indicating similar environmental conditions which in turn should have resulted in similar radon daughter concentrations.

FIGURE 3: Radon Daughter samples in unventilated dead end drifts.



The radon daughter concentrations in the 120 level North which was a very dry dead end drift were also plotted in the figure. The comparison of the values confirms the significance of mine water as the transport medium for radon.

5.2 Ventilation in the Workplace

On the basis of reports and personal recollections we can safely assume, that the only positive ventilation available in the St. Lawrence Corporation mines was compressed air blown into the workplace, or the air from the drills. This became more effective after World War II when the mines changed from 3 shifts to 2 eight hour shifts per day, allowing to blow air for the 4 hours between shifts. However the volume of air was small and inspectors' reports still noted stagnant smoky air in the workplaces. In Director Mine small fans were used in long headings and closed stopes and ventilation raises were more common.

The effect of blown air into a long drift heading was tested by Windish and Little. The results on the 165 level are shown in Figure 4 and 5. The concentrations of radon daughters are plotted from measurements before any airflow is induced and after 4 and 12 hours of blown compressed air. The difference in the slope of the curves and the concentrations between the South drift (Figure 4) and North drift (Figure 5) is due to the dryer conditions in the North drift. The effect of the introduction of a small volume of uncontaminated air is evident. In a small size workplace the level of contamination can be reduced considerably. But back from the workplace the effect of mixing and the introduction of fresh radon gas soon increases the values.

Figures 6 and 7 show the radon daughter concentrations in the South and North drift 4 and 19 hours after the compressed air was turned off. The concentrations at the face in the South drift (Figure 6) built up rapidly reaching over ten times higher values in 4 hours and fifty times higher values after 19 hours. The concentration of radon daughters in the North drift (Figure 7) after 4 and 19 hours increased even more dramatically (100 and 200 times respectively) at the face but more slowly along the drift than in the South drift. This might have been due to a point source of significant inflow of water at the face in the otherwise dryer North drift.

FIGURE 4: Blowing compressed air in a dead end drift.

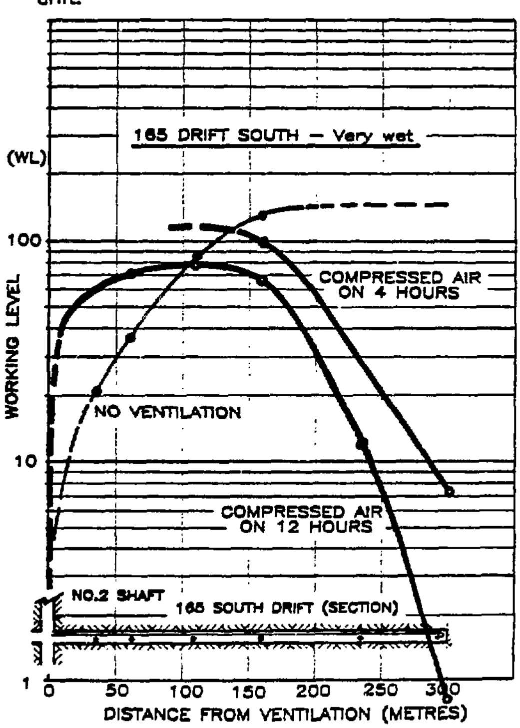


FIGURE 5: Blowing compressed air in a dead end drift.

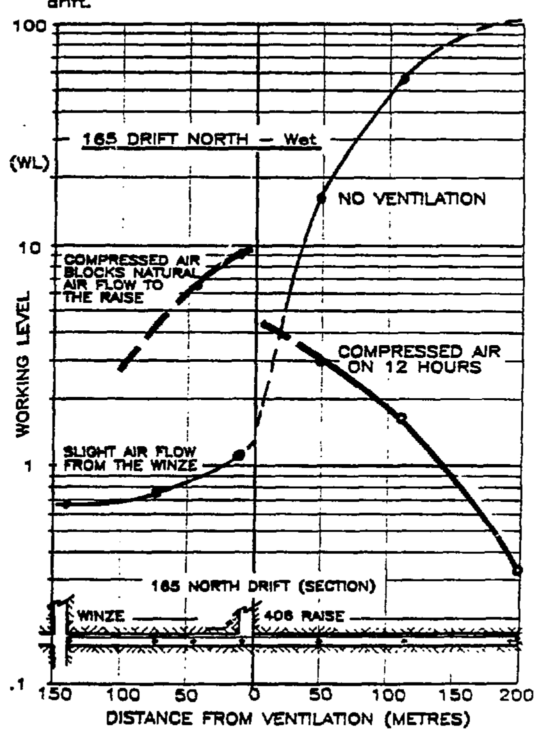


FIGURE 6: Removal of the compressed air ventilation in a dead end drift heading.

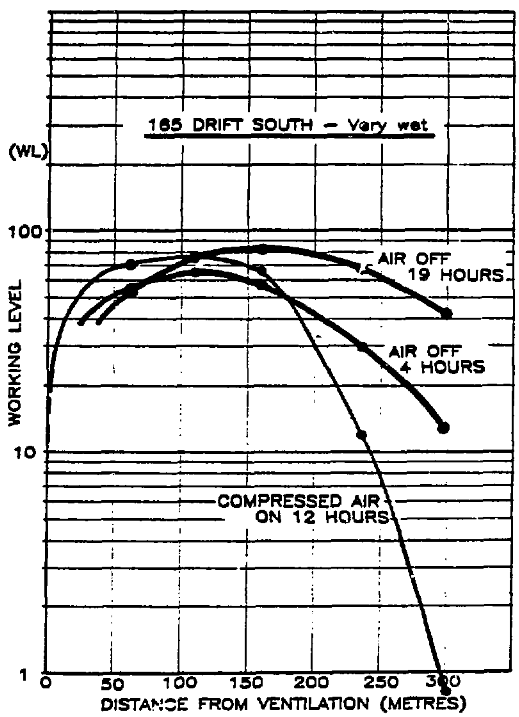
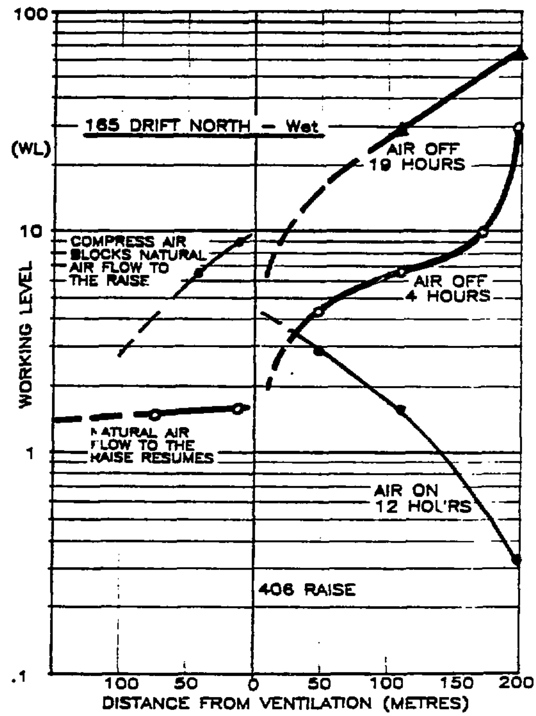


FIGURE 7: Removal of the compressed air ventilation in a dead end drift heading.

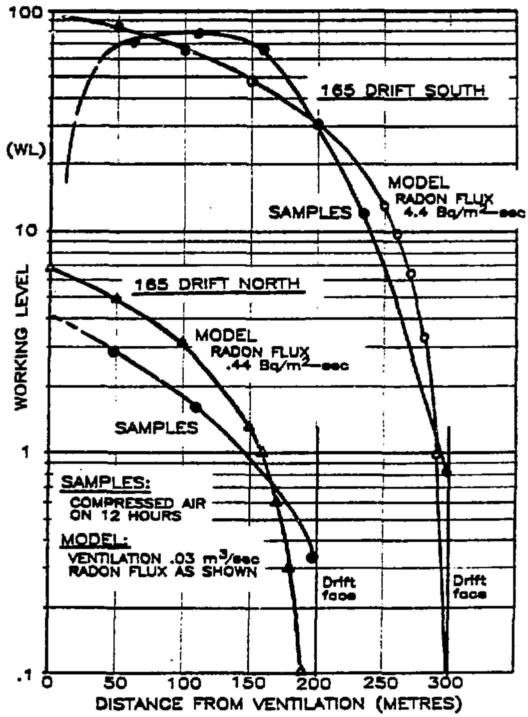


These results indicate, that the ventilating effect of blowing compressed air between shifts disappears very quickly after it is turned off as was usually done at the begining of the shift. During the shift, some ventilation by compressed air occured from the drills during drilling.

5.3 Variation in Radon Emanation

It is known that the South drift on the 165 level was considerably more wet than the North drift and therefore the influx of radon gas into the drift would be much greater in the South drift. In stagnant conditions this does not seem to affect the radon daughter concentration but seems to have a great effect when even a small air movement is introduced. To test this effect, especially the range of radon daughter concentrations for various radon influx rates, a simulation model of these drifts was prepared. The Schroeder and Evans expressions[24] for the growth of radon daughters from the radon in the air and for the decay of radon progeny with residence time were used. The results are shown in Figure 8. The radon emanation rate was estimated from the difference in its concentration in the water freshly released from the rock and in the water in the sumps. Estimates of water inflow volume into the drift were made on the basis of pumping rates in the 165 level. As shown in the figure the rate of increase of radon daughter concentration away from the face is very similar in the South drift for the model and sample values. Also the maximum calculated value is within 25 percent of the maximum sample value.

FIGURE 8: Radon Daughter sample values for a compressed air ventilated drift versus model results for a similar hypothetical drift.



In order to obtain a similar match for the North drift, the estimated radon emanation rate along the North drift had to be lowered by a factor of 10 corresponding with the 10 fold drop in radon daughter concentrations measured between the drifts. This is to be expected as the North drift beyond the access raise was significantly dryer than the South drift.

5.4 Stopes

Unfortunately only one air sample was taken in a stope with the radon daughter concentration 8 WL. The stope had advanced quite high towards the next level and was served by two pillar raises through to the level above. The ventilation was much better than normally found in the mines of the Corporation. Figure 9 shows the diagram and location of the stope. The stope was quite dry as it was well above the bottom level. Even though the stope was ventilated there was a high radon daughter concentration as the air likely travelled through a considerable length of mine openings. In many cases air from old abandoned workplaces leaked into active areas severely contaminating the air. The large open volumes of stopes also contributed to the problem as they would have required a large air volume to flush them out. In many stopes of the Corporation mines there was only the lower entrance up into the stope so air could not circulate. These could then be classed as dead end workplaces.

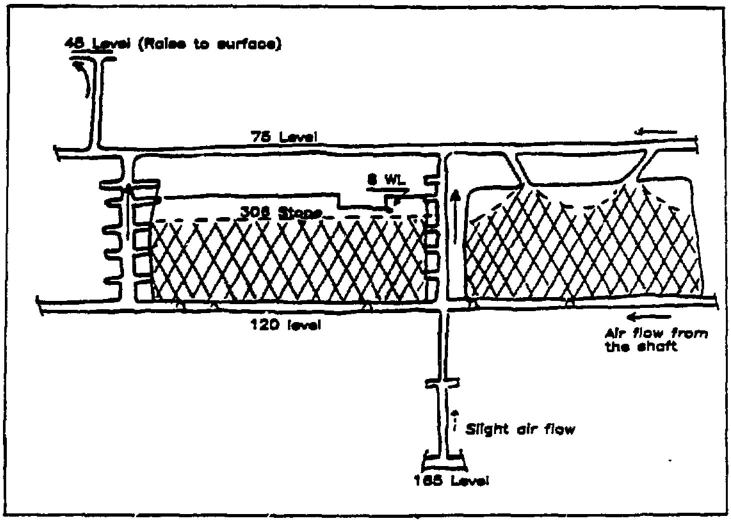


FIGURE 9. Schematic cross section of a portion of the DIRECTOR MINE showing the stope sampled by J.P. WINDISH in 1959. The numerous openings that could have have allowed a good natural draft through this stope is evident.

5.5 Crusher and Loading Pocket

The crusher room had some ventilation to remove dust from the immediate area of the crusher. Radon daughter concentrations from one set of measurements at the crusher were 6.4; 5.8; 4.4; 5.3; and 3.9 WL for an average of 5.2 WL. The loading pocket was measured at 4.0 WL with only very slow air movement detected.

6. BASIC CRITERIA IN ESTIMATION OF RADON DAUGHTER CONCENTRATIONS

The results of extensive measurements at Director Mine[25] were used as the basis for estimation of the ranges of average radon daughter concentration at the other mines.

The available information on the layout of the mine, mining method and working practices was used to estimate the general working environment and to assign the ranges of average radon daughter concentrations.

The following more important criteria were evaluated for the purpose of radon daughter concentration estimation:

i) General mine layout - the length and size of development drifts, and access to the stopes are important factors influencing the amount of natural ventilation;

ii) Amount of water - information on the water inflow, e.g. whether the mine (or its part) was wet or dry, was one of the key factors effecting the radon daughter concentrations. The changes of the water inflow pattern with the progress of mining in various years were also considered;

iii) Mining method - most of the mines used mainly shrinkage stoping with the exception of Director and Tarefare mines, where the cut and fill mining method was used almost exclusively. The Director and Tarefare mines used gravity for the delivery of fill material, and therefore a raise breakthrough preceded mining resulting in more air movement in the stopes. Shrinkage mining did not require a raise breakthrough to the next level above, and in many cases stopes were completely mined out without having the raise broken through to the level above. The ventilation in these stopes was practically nonexistent. The Iron Springs Mine used this method almost exclusively;

v) General working conditions - the known capacity of the compressed air system, availability of electricity for the compressors, water handling procedures, and pumping arrangements had a significant influence on the amount of ventilation between shifts and on the amount of radon released into the mine environment. Considerable evidence of the working conditions in different mines at different times was presented in the Royal Commission hearings and in other documents. The mine inspectors visiting the mines from time to time provided helpful information in their written reports.

7. ESTIMATION OF RANGES OF AVERAGE RADON DAUGHTER CONCENTRATIONS

The analyses of the Windish and the Little survey results were used to develop Table 1 as ranges of radon daughter concentration estimates for the various workplace environment conditions. Based on the historical records, expected work environment conditions were then modeled for each mine for each year of its operation.

TABLE 1

Ranges of Radon Daughter Concentrations for Various Workplace Conditions (in WL)

Workplace Conditions	Very Wet	Wet	Dry
Not Ventilated	80 - 130	50 - 80	2 - 5
Ventilated between shifts	10 - 50	10 - 50	1 - 3
Compressed air during shift or thru ventilation	7 - 15	1 - 10	1 - 3
Ventilated by a fan	5 - 15	1 - 5	1 - 3

Based on this modeling, the appropriate range from Table 1 was used according to established mine specific conditions to develope Tables 2 and 3. These show the estimated average ranges for the individual mines by years.

The ranges do not represent extreme concentrations, but are average workplace concentrations for high, medium and low areas. As the type of work usually dictates the place where a man works and his working environment conditions, it is possible to place the job types within certain average concentration ranges.

i) High Average Range - represent the prevailing conditions for drift and raise (development) miners. They worked in remote areas of the mine, frequently in dead end headings with the worst ventilation conditions. Reports of these workers being gassed or suffering from oxygen deficiency were frequent, mainly in the earlier years.

ii) Medium Average Range - would be applicable for stope miners. As they worked in one area for an extended period, more care was likely taken to provide rudimentary ventilation. However, as the stope progressed up towards the next level, without a broken-through raise, it became more difficult to provide fresh air. The stopes usually had two entrances from below, but not until the later years was there always a raise through to the level above to provide air flow.

iii) Low Average Range - represent prevailing conditions in the established areas of the mine, mostly near an air circuit, such as down a shaft, along a level and up through an old stope to surface. Workers around the shaft, trammers and those in certain special jobs, such as crusher operators and pumpmen were working in these conditions if their workplaces were not shut off from the air circuits (behind doors).

Tables 2 and 3 also list some events at the mines, that would have significant effect on the ventilation. There were some small properties, of the St. Lawrence Corporation, where mining was carried on for only a few years. As they were close to the surface it is doubtful if the radon daughter concentrations were significant. Some of the small veins are listed in Table 4.

8. CONCLUSION

During the review, the writers found sufficient information to gain a reasonably good understanding of the mining activities at the individual mines in specific years and to be able to model the corresponding working environment conditions.

Better knowledge of the ventilation and radiation conditions at the Director mine after 1960 exists. This data and the experience from other mines with radon daughters present and using more advanced techniques for assessment of radon daughter behaviour in mine atmospheres, enabled the writers to estimate more realistic and technically justifiable the likely ranges of average radon daughter concentrations.

The uncertainties are always great in any retrospective evaluation. The writers would therefore not recommend the use of single-valued estimates. They would imply a degree of confidence, which cannot exist in these evaluations. The use of average ranges of concentrations provides a much better indication of the uncertainties involved.

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TABLE 2

Newfoundland Fluorspar Limited
(later, ALCAN, Newfoundland Fluorspar Works)

Estimates of Workplace Radon Daughter Concentration Range by Year (WL)

Mine	Director			Tarefare		
	Averages			Average		
	Low	Medium	High	Low	Medium	High
1939	5	20	50	5	15	50
1940	5	20	50(1)	--		--
1941	10	25	50	--		--
1942	10	25	50	--		--
1943	5	20	40(2)	--		--
1944	5	15	40(1)	10	20	30
1945	5	15	40(3)	10	20	40
1946	--	--	-	10	20	40
1947	--	--	-	8	15	40
1948	3(4)	15	20	-	--	--
1949	3	10	15(5)			
1950	2(6)	5	10(7)			
1951	2	5	10			
1952	2	5	10(8)			
1953	2	5	10			
1954	2	5	10(9)			
1955	1(10)	4	10(11)			
1956	1	4	10			
1957	1	4	10			
1958	1	4	10(12)			
1959	1	4	10(13)			
1960	1	4	10			

NOTES

1) extensive dead end drifting
2) Large scale stoping started, no. 2 shaft to the 75 level
3) allowed to flood late in the year, 3 weeks to fill
4) extensive ventilation raising begun, 2 shift operation
5) new shaft and levels
6) upper levels getting dryer
7) increased use of small fans, vent raises
8) extensive development from the South shaft
9) South vent raise finished
10) ventilation introduced for diesel tramming
11) development on the 120 level
12) renewed drift development 165 level
13) reduced development

TABLE 3

St. Lawrence Corporation Mines

Estimates of Workplace Radon Daughter Concentration Range by Year (WL)

Mine	Black Duck #1			Blue Beach			Hares Ears		
Year	Averages			Averages			Averages		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
1935	2	10	20	2	3	5			
1936	10	20	50(1)	5	7	10			
1937	20(2)	30	50	5	10	20			
1938	20(3)	30	60	5	15	30			
1939	20	30	60	5	20	30			
1940	20	25	60	10	30	50(1)			
1941	20	25	60	10	30	50			
1942	--	--	--	10	20	40(2)			
1943				10	20	40	2	2	5(1)
1944				10	20	40	2	2	5
1945				10	20	40	5	5	10
1946				10	20	40	-	-	--
1947				10	20	40	-	-	--
1948				10	20	30	-	-	--
1949				10	20	30	-	-	--
1950				10	20	30	-	-	--
1951				5(3)	15	30	-	-	--
1952				5	15	30	-	-	--
1953				5	10	20(4)	-	-	--
1954				5	10	20	-	-	--
1955				5	10	20(5)	-	-	--
1956				5	10	20	10	15	30(2)
1957				5	10	20	10	20	40
1958				--	--	--	10	20	40(3)
1959							10	20	40
1960							10	20	40

NOTES

Black Duck #1

1) Drift out from East shaft
   - wet, gassy, remote workings
2) underhand stopes,
   - no vent raises
3) 2 small blowers (22 CFM) used, stoping only.

Blue Beach:

1) Begin to develop stopes still upper levels

Blue Beach: (Cont'd)

2) started to blow air, but more remote development
3) some raises, shaft work
4) begin to develop South shaft
5) inspectors report poor conditions.

Hares Ears:

1) Short development, dryer mine
2) remote drifting
3) remote stopes, more water.

TABLE 3(Cont'd)

St. Lawrence Corporation Mines

Estimates of Workplace Radon Daughter Concentration Range by Year (WL)

Mine	Haypook			Iron Springs			Red Head		
Year	Averages			Averages			Averages		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
1935				2	7	10			
1936				15	20	50(1)			
1937				10	20	25			
1938				5	10	15(2)			
1939				20	30	50(3)			
1940				20	40	80			
1941				20	40	80			
1942				20	40	60(4)			
1943				15(5)	25	60			
1944				15	25	60			
1945				15	25	60			
1946				15	25	60			
1947				15(6)	20	40			
1948				15	20	40			
1949				15	20	40			
1950				15	20	40(7)			
1951				10	15	30			
1952				5	15	25(8)			
1953	20	30	50(1)	5	15	20(9)			
1954	20	30	50	5	15	20			
1955	20	30	50	5	15	20			
1956	20	30	50	--	15	20			
1957	10	15	30(2)		--	--			
1958	10	15	30						
1959	10	15	30				5	10	30(1)
1960	10	15	30				5	10	30(2)

NOTES

Haypook Vein:

1) Initial development very remote from Blue Beach Level
2) raise to surface, new shaft.

Iron Springs:

1) Small shafts and some underhand stopes
2) back to open cut
3) underground at East shaft - start large overhand stopes
4) started to blow air

Iron Springs (Cont'd)

5) the only ventilation raise finished
6) inspector reports some natural draft on main level
7) inspector reports no ventilation on development level
8) inspector reports great improvement, a number of new internal vent raises
9) still many complaints of no ventilation at headings.

Red Head:

1) Not very deep, stopes broke through to surface
2) some lower level development

TABLE 4

Small Vein Operations of the St. Lawrence Corporation

Name of Vein	Radiation Daughter Concentration Estimates (WL Averages			Remarks
	Low	Medium	High	
Black Duck #1	5	8	20	dry, 1943/45
Rosy Ridge	2	3	5	dry adit 1956/57
Lord and Lady Gulch	2	5	10	very little water, all stopes through to surface 1948/57
Grassy Gulch	5	8	10	small shaft, wet 1950/52
Scrape	0	2	5	open cut 1937/41
Valley Vein	2	5	10	small shaft, ventilated 1960/61

Numerous other small vein exploration operations on surface or short adits with very low concentrations.

REFERENCES

1. de Villiers, A.J., Windish, J.P., 1964, Lung Cancer in a Fluorspar Mining Community.I. Radiation, Dust and Mortality Experience", Brit. J. Industr. Med., Vol. 21, pp. 94-109.

2. Wright, E., Couves, C., 1977, Radiation-induced Carcinoma of the Lung - the St. Lawrence Tragedy, J. Thorac Surg. Vol. 74, pp. 495-498

3. Morrison, H., Wigle, D., Stocker, H., de Villiers, A., 1981, Lung Cancer Mortality and Radiation Exposure Among the Newfoundland Miners, Proceedings of Internation Conference on Radiation Hazards in Mining: Control, Measurement and Medical Aspects, pp. 272-276, Golden, Colorado.

4. Dory, A.B., Practical Difficulties Related to Implementation of ICRP - Recommended Dose Limitation in Uranium Mines, International Atomic Energy Agency, Vienna, 1979, IAEA-SR-36/7.

5. Report of Royal Commission Respecting Radiation, Compensation and Safety at the Fluorspar Mines, St. Lawrence, Nfld. 1969, pp. 17-32

6. Leyton, E., Dying Hard, Toronto, 1975 McClelland and Stewart

7. St. Lawrence Workers' Protective Union, Brief to the Royal Commission Respecting Radiation, Compensation and Safety at the Fluorspar Mines, St. Lawrence, Nfld., 1968. Partial document found at the Newfoundland Archives.

8. Copies of Mine Inspection Reports submitted to the Various Newfoundland Governments, 1936 to 1959 obtained from the Publications and Information Section, Department of Mines and Energy, Government of Newfoundland and Labrador.

9. Health Hazards in the Mines of Newfoundland; report of the Occupational Health Division, Department of National Health and Welfare, Ottawa; J.P. Windish: Vol I, May 2, 1958: Vol II, Aug 1, 1958.

10. Newfoundland Fluorspar Ltd., Submission to the Royal Commission Investigating Health and Radiation Conditions and Matters Involving Workmens Compensation at St. Lawrence, Nfld., 1967, Appendix 'J'.

11. Health Hazards in the Mines of Newfoundland; Vol. III, Radiation Levels in the Workings of the Newfoundland Fluorspar Limited, May 9, 1960.

12. Report of the Royal Commission, p. 29.

13. Newfoundland Fluorspar Ltd., Submission, p. 107.

14. Health Hazards in the Mines of Newfoundland, Vol. III, pp. 14-16.

15. Report of the Royal Commission, pp. 43-52.

REFERENCES (Cont'd)

16. The Measurement of Airborne Radioactivity in Director Mine, Newfoundland Fluorspar Limited, St. Lawrence, Nfld., May 3, 1960; An investigation performed for the Aluminium Laboratories Limited, Montreal, by Arthur D. Little Inc. USA. pp. 13-15
17. Newfoundland Fluorspar Ltd., Submission, pp. 107-108.

18. Report of the Royal Commission pp. 17-33.

19. Leyton, E. ...

20. Mine Inspection Reports, Government of Newfoundland ...

21. Newfoundland Fluorspar Ltd., Submission, pp. 15-73.

22. Report of the Royal Commission, pp. 20-27.

23. Health Hazards in the Mines of Newfoundland, Vol III, Table 2.

24. Evans, R.D. and Schroeder, G.L., 1960, "Some Basic Concepts in Uranium Mine Ventilation", Transactions of the Society of Mining Engineers, AIME, Vol. 244.

25. Dory, A.B., Ventilation Systems as an Effective Tool for Control of Radon Daughter Concentration in Mines, Proceedings of International Conference on Radiation Hazards in Mining Control, Measurement, and Medical Aspects, October 1981, pp. 155-160, Golden, Colorado.