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RADON LEVELS FOUND IN MINES IN NEW YORK STATE*

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By

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The purpose of this paper is to present the results of a study of the levels of air-borne radioactive substances in various underground working places in New York State. These include operating mineral mines, an abandoned iron mine, and a sight-seeing cavern, none of which is associated with any known uranium deposit.

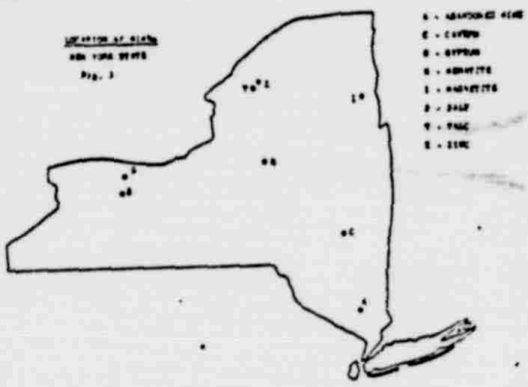
The study indicated the possible presence of radon and radon daughters in the air of any mine in amounts in excess of accepted standards for maximum permissible concentrations. Re-evaluation of these standards was indicated.

Previous studies of radon levels in non-uranium mines in the Colorado plateau(1) have indicated that concentrations comparable to those found in the uranium mines in that area by Holaday and associates could be expected. The reports on the Colorado studies raised the question whether this situation was peculiar to that area. For this reason, it was decided to sample some underground operations in New York State to determine whether levels of this order could be found in non-uranium mines, in regions not known to contain profitable uranium deposits.

MINING IN NEW YORK STATE

Several geological studies had failed to locate any appreciable deposits of uranium ore in New York State up to the time of this investigation(2,3). Other minerals have been recovered from open-pit and underground workings within the state for many years, the main product being cement, although magnetite, gypsum, talc, salt, hematite, limestone, clay, slate, and zinc are mined in smaller quantities. At the time of this study there were 22 active underground mines and many more open-pit operations. In addition, many abandoned mines may still be entered and are being used for the growing of mushrooms or for underground storage.

Figure 1 shows the location of the work places included in this study. Samples were taken throughout the State, in at least one underground mine of each type still in operation. The depths varied from 35 feet (10 m) to more than 2,000 feet (609 m) below the surface of the ground. Some of the mining is of the pillar and room type operation, and some ores are recovered by drift mining. Although the quality of the ores is generally excellent, the quantities obtained are small, and the number of workers involved number in the few hundreds.



MINING POPULATION

Many of these operating mines have been worked continuously since the Civil War, and hence, the mining population of the district can trace its history through several generations. Any radiation exposure conditions found today would indicate the possibility of past and continued exposure to small communities for several generations.

In addition, medical data are available on many of these groups as a result of past occupational exposure studies on silicosis by the Division of Industrial Hygiene and others(4). Suitable engineering methods were developed to control silicosis as a result of these earlier studies, although no measurement of radiation exposures had been attempted prior to this time.

SUMMARY OF EXPOSURE CONDITIONS

The on-the-spot analysis of collected dusts indicated that the air-borne radioactivity was essentially short-lived, alpha-emitting material. The half-life, after a few moments, was approximately 30 minutes. A possibility of thoron and its decay products existing in some small degree has not been completely ruled out. However, for the purpose of this study, the radioactive mate-

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rial in the dust samples was considered to consist essentially of Radon 222 decay products in the Uranium series. Table I is a tabulation of this series showing the decay products, their halflifes, and their principal radiations.

TABLE I—URANIUM SERIES (4N + 2)

Element	Decay Products	Half-Life	Principal Radiations
U^{238}	Uranium I	4.51×10^9 yr.	Alpha
Th^{234}	Uranium X_1	24.1 days	Beta, Gamma
Pa^{234}	Uranium X_2	1.14 min.	Beta, Gamma
U^{234}	Uranium II	2.32×10^5 yr.	Alpha
Th^{230}	Ionium	8.3×10^4 yr.	Alpha
Ra^{226}	Radium	1,600 yr.	Alpha
Rn^{222}	Radon	3.83 days	Alpha
Po^{218}	Ra A	3.05 min.	Alpha, Beta
Pb^{214}	Ra B	26.8 min.	Beta, Gamma
Bi^{214}	Ra C	19.7 min.	All types
Po^{214}	Ra C'	1.5×10^{-4} sec.	Alpha
Tl^{210}	Ra C''	1.32 min.	Beta
Pb^{210}	Ra D	22.2 yr.	Beta, Gamma
Bi^{210}	Ra E	4.97 days	Alpha, Beta
Po^{210}	Ra F	139 days	Alpha
Pb^{206}	Ra G	Stable	

Radon is a gas evolved during the disintegration of its parent, Radium 226, which has been formed through the earlier disintegration of products in the series beginning with Uranium 238. The radon decays through a series of other isotopes to stable lead. These daughter isotopes apparently adhere to the solid dust nuclei in the radon atmosphere. Recent considerations of the hazard from radon indicate that the hazard potential of these daughter products is appreciable and may contribute the greater part of any exposure delived to the bronchial epithelia.

The ratio of these decayed products to the original quantity of radon is influenced in part by the ventilation in the area sampled(5). Since a large part of the hazard depends upon the presence of these decay products, it would similarly depend upon their ratios to the parent and to each other. For this reason, any sampling of the air for the decay products, in order to extrapolate the findings to determine the quantity of radon present, must recognize the need for determining the ventilation conditions. Dead end drifts were sampled primarily where the ventilation was effectively zero, and it could be assumed that the decay products were essentially in equilibrium with any radon present. The dust loading of inert nuclei in the air may also influence the measurement of radon when sampling for the decay products. Some minor deviations between the value of the radon concentration using the flask method and the daughter product analysis might be explained in this manner. However, no opportunity to make a test of this hypothesis was available.

Sample Techniques

Sampling for air-borne material consisted of filtering dust with Whatman No. 41 filter paper and the simultaneous collecting of gaseous components directly in standard one liter glass flasks obtained from the New York Operations Office of the Atomic Energy Commission. The filter-paper sample was counted immediately with the use of a Samson Alpha Survey meter carried down into the mine for this purpose. (No indication of contamination of the instrument which could not be adjusted out of the measurement was noted.) When these instantaneous readings of the filter-paper samples indicated the presence of appreciable quantities of radon daughters, samples of the ground water and the ore were collected and later analyzed for the parent Radium 226.

The lower limit of sensitivity of the collecting system using the filter paper was in the order of 10^{-12} curies per liter of radon and the upper limit was approximately 10^{-5} curies per liter. The dust was collected using two different sources of air movement: an MSA Samplair hand pump or a battery-operated Gast pump. Using the Samplair, dust was collected from a volume of 30 liters for a period of two minutes. The battery-operated pump collected a sample from 50 to 75 liters for a period of 10 minutes. All calculations have been corrected for the difference in time required to collect these samples. The flasks were later analyzed directly for radon at the New York Operations Office.

Results

The concentrations of radon in these mines were determined from the collection methods mentioned above. The dust samples of the daughter products were used to calculate radon levels by two methods. The first consisted of a straightforward conversion from disintegrations per minute per liter to curies per liter using correction factors for collection efficiency and for self absorption of alpha particles in filter paper. The sceond

TABLE II—RADON CONCENTRATIONS IN MINES IN NEW YORK STATE

Area	Type	Concentrations in 10^{-11} Curies per liter		
		Conversion*	Calculated†	Flask‡
A	Gypsum	2.0 - 15.0	1.4 - 11.1	1.2 - 11.0
B	Iron Mine	4.1 - 14.2	4.7 - 10.6	3.3 - 4.1
C	Iron Mine	6.9 - 11.2	5.3 - 8.5	3.2 - 3.7
D	Talc Mine	1.6 - 6.2	1.2 - 4.6	2.0
E	Hematite Mine	2.1 - 5.2	1.6 - 4.0	lost in counting
F	Talc Mine	1.5 - 1.7	1.0 - 1.3	0.8
G	Iron Mine	0.7 - 1.7	0.5 - 1.3	0.2 - 1.2
H	Talc Mine	0.6 - 1.6	0.4 - 1.2	0.8
I	Zinc Mine	0.2 - 0.6	0.1 - 0.4	0.01 - 0.1
J	Zinc Mine	0.1 - 0.3	0.1 - 0.2	0.01 - 0.1
K	Zinc Mine	0.28	0.21	0.21
L	Gypsum Mine	no noticeable reading		0.13
M	Rock Salt Mine	no noticeable reading		0.05
N	Abandoned Mine	no noticeable reading		0.01

* These figures converted directly from disintegration per minute per liter, on filter paper samples of dust.
† This column calculated from same data as the conversion figures using a formula developed by Dr. J. Harley (NYOO AEC).
‡ These figures obtained from direct sampling for radon using one liter glass flasks, and counting electronically.

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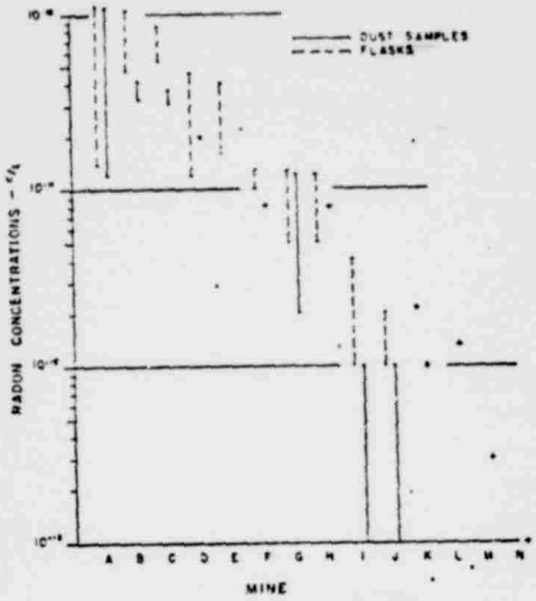


Fig. 2

calculation used a formula developed by Dr. John Harley of the New York Operations Office (A.E.C.) for this same purpose(6). The two calculations agreed reasonably well with each other and in some instances exceptionally well with the concentrations as determined by the direct method. This direct method, using the one liter glass flasks, was considered the more reliable technique for the measurement of radon concentrations for this study.

The results of these calculations and the comparisons with the direct sampling results are shown in Table II (also Figure 2). It can be observed that radon levels between 10^{-10} and 10^{-11} curies per liter were present in the majority of places sampled. The flask sample for Mine E was, unfortunately, lost during the transfer of the sample to the ionization chamber of the counting equipment.

Discussion

The data taken as part of this study appear to be most significant when it is recalled that New York State had never been considered to be an area where profitable uranium might be discovered. This is in direct contradiction to the situation in Colorado where the entire state has been suspect for uranium. As can be seen from the data, radon concentrations in high levels have been found in many sections of New York State.

This would indicate that any underground working area might present a similar picture. Should this be true, persons in the field of occupational health, and particularly those interested in the health of mining populations, are confronted with the need to evaluate the possible radiation environment in these mines and to study the possible effects from these exposures. Mining operations need not be the only places where employees predominantly underground would be exposed to significant amounts of radiation. One of the locations sampled was an underground cavern used for sight-seeing. The public which enters this area would remain in the radiation atmosphere for short periods of time. However, the guides and repairmen would be exposed to these concentrations the greater part of each day for several years. The exposure of persons employed in the growing of food products in abandoned caves or mines or in underground areas used for the storage of valuables may be similarly considered.

The consistent finding in many mines, not exclusively those containing known uranium workings, by this and other studies, of radon concentrations in excess of 10^{-11} curies per liter requires considerable attention by those interested in the application of reasonable maximum permissible concentrations. If the limit of 10^{-11} curies per liter for radon is correct, many of the mines in this study would be required to consider an increase in their air supply by significant amounts. If a permissible level of 10^{-10} curies per liter is accepted, the need for financial outlay for this additional ventilation can be reduced, but the mining population may be subjected to a continuing excessive radiation exposure, one arising from the presence of naturally occurring radioactive material. Recent recalculation of the exposure of the bronchial epithelial to radon and its daughter products indicates that a worker breathing in a radon level of 10^{-10} curies per liter for a normal work week may receive an exposure of 22.6 rem per week(7). This would appear to be an unreasonable exposure to permit to continue once its possibility is known, although many authorities feel that 10^{-10} curies per liter must be regarded as the only practical limit at this time(8).

In order to complete this study, all mines and suspected underground areas will be sampled as time permits. Similar studies might be initiated in other states and a central committee could endeavor to evaluate the overall data to determine its hazard potential, the selection of a proper exposure limit, the possible origin of the radon and practical control methods.

Correlation

In attempting to develop a predictable correlation no clear cut relationship to any single physical factor has been obtained. It would appear that the concentrations were highest in locations where the ore body surrounding the working area was small or negligible. In the largest mine sampled, a considerable ore body was present and the concentration of radon was practically non-existent.

The deepest mine in this study did not indicate the highest concentration of radon, and those near the surface of the earth did show very important exposure characteristics. When the concentrations in the working openings are examined in relation to the extent of the surrounding ore body, it may be noted that those mines enveloped by considerable minerals show the lowest levels.

This may be explained on the theory that radon is constantly being emanated from uranium (and radium) deep within the earth. This radon diffuses upward through the earth's crust by gas pressure from below. Where an extensive mineral body surrounds an air pocket, the radon is prevented from escaping and must pass around the ore. Where minor ore concentrations exist, the radon diffuses in quantity into the working-area air,

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and then maintains effective equilibrium with its decay products in dead-end drifts where ventilation is at a minimum.

Many phenomena have been observed in other fields of investigation which indicate the probable presence of uranium and its decay products in more significant amounts as one proceeds deeper into the earth.

Attempts to utilize underground areas for neutron study have shown that a heavy increase in neutron production occurs at levels deeply below the surface of the earth(9). The greater part of this neutron flux comes from below, leading to the assumption that the radiation originates in the center of the earth, possibly from the spontaneous fission of ordinary uranium or thorium.

Reports have been published which indicate the ability to locate oil fields from the air by mapping out background radiation levels detected by a scintillation counter in a plane flying at a uniform height over the suspected regions. The radiations were again assumed to be originating within the earth, effectively casting a shadow of the oil field, which may be traced with the use of sensitive radiation detectors.

Recent studies of the radium content of sea water with depth and of the presence of uranium in volcanic ash indicate that there is reason to believe the existence of much greater concentrations of uranium and decay products as one proceeds closer to the earth's center. Several factors determine the clumping of this radiation and uranium in sea water, although higher concentrations at lower depths appear a good generality.

The collection of helium in quantity has been considered as indicating the presence of large quantities of either uranium or thorium in subsurface rock. This helium is thought to be radiogenic, particularly since uranium decay-product material, such as radium, has recently been found in this subsurface rock in helium-producing areas. The radioactivity studies in some oil fields have concluded that abnormal quantities of uranium must be present in subsurface rock, although its exact distribution and location have not been determined(10).

Conclusions

The value presently being used for maximum permissible concentration of radon and radon daughter products of 10^{-11} curies per liter may be exceeded in underground work areas as a result of the presence of natural radioactive parent materials. The concentrations may be of such nature as to present a significant hazard to those exposed. This would appear to be true in any underground work area in any section of the country, regardless of the absence of mineable uranium.

The data indicate that the determination of radon concentrations can be suitably made by sampling for the short-lived daughter products. It appears that these decay products attach to dust nuclei in the air, that their relative concentration is affected by the ventilation present, and that their total activity may be related to inert dust loading (including particle size distribution) in the air. In this study all dust samples analyzed for radon decay products agreed reasonably well with the direct gas samples, and any error appeared to be on the safe side. The dust sampling technique should be further developed as a replacement for the rather expensive flask system for measuring radon concentrations.

The author would like to acknowledge the kind assistance and suggestions of the following members of the Division of Industrial Hygiene: Dr. Irving R. Tabershaw, Dr. Morris Kleinfeld, Mr. George Paul, Mr. Arthur Stern, Mr. Milton Sheinbaum, and Mr. Benjamin Dolin.

The Chemical Engineering Unit of the Division performed the separation of radium parent materials from samples of ore and water in order that attempts could be made to correlate these findings with the air samples. The New York Operations Office of the A.E.C. provided the sample flasks and other specialized equipment and performed the radioanalysis of the collected samples.

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A New Brochure

The Building Plans Unit of the Division of Industrial Hygiene has prepared a brochure entitled "Information Relating to the Submission for Approval of Plans and Specifications for Construction or Alteration of Buildings." This brochure is numbered IH-420, and may be referred to by that number.

Plans for certain types of buildings to be erected within this state must be approved by this Division prior to their construction. Instructions and explanations contained in the booklet make it possible for individuals and corporations who are about to build in this State to comply with all the provisions of the law without possibility of incurring penalties, and, at the same time, prevent the necessity for expensive alteration of structures which are not in accordance with the requirements.

All interested individuals and corporations may procure free copies of the brochure by making their requests of the New York State Department of Labor, Division of Industrial Hygiene, Building Plans Unit at either the Governor Alfred E. Smith State Office Building, Albany 1, New York, or 270 Broadway, New York 7, New York.

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