AN INTERIM REPORT

of a

HEALTH STUDY OF THE URANIUM MINES AND MILLS

by the

FEDERAL SECURITY AGENCY
Public Health Service
Division of Occupational Health

and the

COLORADO STATE DEPARTMENT OF PUBLIC HEALTH

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FOREWORD

The Division of Occupational Health, U. S. Public Health Service, in conjunction with the Colorado Department of Public Health, has been conducting a health study in the uranium mines and mills since July 1950. Although the study is far from complete, sufficient information has been derived to conclude that certain acute conditions are present in the industry which, if not rectified, may seriously affect the health of the worker. We therefore believe it essential that an interim report be issued to the operating companies, describing the progress of the study and presenting methods for correcting any potentially harmful conditions.

It has been gratifying to note that the operating companies, as a result of oral recommendations by our technical personnel, have already started to correct some of these conditions. These diligent efforts must be continued, however, to free the mines and mills of all major health hazards.

I wish to take this opportunity to express my appreciation to the operating companies for their assistance and cooperation in the conduct of this study and to solicit their continued aid in future studies that must be made in order to successfully culminate this project.

Seward E. Miller, Medical Director
Chief, Division of Occupational Health
U. S. Public Health Service
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INTRODUCTION

Between 1881 and 1887, ores, later found to be radioactive, were discovered on the Colorado Plateau in the Rocky Mountain area of the United States. These were carnotite ores which contained vanadium and uranium, with a small quantity of radium. Several mines were developed during this period, but production was small as there was little or no demand for these materials. A small amount of ore was exported to Europe, and it is reported that the Curies used American carnotite ores in their early experiments.

In 1912, the U. S. Bureau of Mines surveyed the carnotite deposits of the Colorado Plateau and reported them as a practical source of uranium ore. The Bureau of Mines also made a study of methods for recovering radium, vanadium, and uranium from these ores and operated a pilot plant to demonstrate methods of production. From 1916 to 1923, the domestic production of radium from carnotite ores was significant. In 1923, however, when radium became available from high grade Belgian Congo ores, the low grade American ores were no longer competitive. 1,2,3

The development of atomic energy focused attention and interest on the carnotite deposits of Colorado and Utah. During the life of the Manhattan Project, many of the old tailings dumps were reworked for their uranium content. Beginning about 1946, the discovery of many new ore bodies in the Colorado Plateau caused the industry to mushroom in this area. At the present time, there are an undetermined number of mines mining uranium ores of various types on the Colorado Plateau. These ores are the carnotites, which have been recognized for many years, roscoelite, autunite, uranite, and torbernite. The State of Colorado presently has the greatest production of uranium ores, with sizeable quantities also mined in Utah, New Mexico, and Arizona. New discoveries, as yet undeveloped, have been reported in Montana and Wyoming. There are eight mills engaged in the processing of the uranium ores, which produce as their final products uranium oxide and vanadic acid. The uranium oxide is shipped to other establishments controlled by the Atomic Energy Commission for refining and subsequent separation of the isotopes.

In August 1949, when the industry had reached a sizeable production rate in the State of Colorado, Dr. Roy L. Cleere, Executive Secretary, Colorado Department of Health, appointed an advisory board to advise him and the State Division of Industrial Hygiene on the procedures to be used in conducting studies and surveys in this industry. Among the conclusions drawn at the first meeting of this group were that little or nothing was known of the health hazards of the uranium producing industry, and that a medical reconnaissance survey should be made by a physician from the Division of Industrial Hygiene* of the U. S. Public Health Service.

* Now known as the Division of Occupational Health
Such a reconnaissance survey was made shortly after this meeting. On August 25, 1949, Dr. Cleere called a second meeting of the Advisory Committee, at which was also represented the management of the larger companies mining and producing uranium in the State of Colorado. This group concluded that, in view of the dearth of available information on the health hazards associated with this industry, the Division of Industrial Hygiene of the U. S. Public Health Service should be requested to conduct a study of the uranium mines and mills. Accordingly, on August 30, 1949, a formal request for such a study was made to the Surgeon General by the Colorado Department of Health, the Colorado Bureau of Mines, the Colorado Industrial Commission, and several companies engaged in uranium mining and production. Shortly thereafter, the Chief of the Division of Industrial Hygiene, U. S. Public Health Service, replied to these agencies, expressing the desire and willingness of the Division to conduct a study of this type.

While these negotiations were underway, the Industrial Hygiene Field Station* of the Public Health Service conducted a very limited study of the mining problems in the mines located on the Navajo Indian Reservation. The preliminary information obtained in this brief study indicated that the miners were exposed to external radiation, radon gas, and a high silica dust containing an undetermined amount of radioactivity. In addition, it appeared that the uranium and vanadium contained in the dust were of toxicologic importance and also that the matter of internal radiation due to the inhalation of radioactive dust should be considered.

Shortly thereafter, a preliminary survey was made of a mill producing uranium oxide and vanadic acid. The findings revealed that the mill workers were exposed to uranium- and vanadium-containing dust and to fume and dust of the isolated uranium and vanadium. It was determined that radon was of little significance in the mills because of the large area available for dilution of the gas; that external radiation was not an apparent problem; but that it would be necessary to consider the internal radiation factor, since dust control in the mills was not too effective.

With this background of information, it was concluded that the health study should consist of two essential and correlated phases: a medical investigation and an environmental investigation. Approximately 700 workers were given medical examinations in the first phase of the study, extending from July to October 1950. During the 1951 season, approximately 1,160 men were examined, of whom 260 were miners and 200 were mill workers. During the two seasons, physical examinations have been performed on 1,117 persons. This is the maximum number of men that could be readily examined at this time, for the remaining persons are employed at locations so remote that it would be impracticable for a medical team to get to them. However, it is believed that this coverage represents a

* Now known as the Field Station, Division of Occupational Health
large enough segment of the working population to permit the drawing of valid conclusions. Since the mines and mills are frequently located at extremely remote locations, it has been necessary to confine the study to the summer and early fall months in order to avoid adverse weather conditions.

The medical study consisted of a detailed physical examination, a chest X-ray, and clinical studies of the blood and urine. The environmental phase included the determination of the nature and concentrations of the materials to which the workers were exposed. Through a correlation of these data, it was hoped that information could be obtained on the health hazards associated with the industry so that necessary control procedures could be instituted.

Environmental studies have been made in six mills and approximately fifty mines. These studies consisted of an evaluation of the dust problem, especially with relation to the silica content of the dust; a determination of the nature and extent of exposure to toxic materials such as uranium, vanadium, and other mineral constituents of the ore; and an evaluation of the radon concentrations in the mines.

Acknowledgments

In order to conduct this study, the Division of Occupational Health, U. S. Public Health Service, has cooperated very closely with the Atomic Energy Commission, especially the Division of Biology and Medicine and the Health and Safety Division of the New York Operations Office. The various state health departments concerned, i.e., Colorado, Utah, New Mexico, Arizona, have been advised of the progress of this study and in many cases have given us valuable cooperation. Assistance has been provided by the U. S. Bureau of Mines, and certain analytical work has been performed by the Los Alamos Scientific Laboratory, the Navy Radiological Defense Laboratory, and the U. S. Bureau of Standards.

Particular acknowledgment is made of the assistance which the Colorado Department of Public Health has given in the conduct of this study. The contribution of the National Cancer Institute through specialized consultation, as well as grants to the Colorado Department of Public Health, is also gratefully acknowledged.

II

EXPERIENCE IN EUROPEAN MINES

In the mines of the Erz Mountains, on both the Bohemian and Saxon sides, it has been known for centuries that the miners die in the prime of life with symptoms of damaged lungs and rapidly progressing ill health. These conditions, especially well known at the Schneeberg mines in Saxony,
have been mentioned or described by many writers, including Agricola in 1500, Matthesius in 1559, and Pansa in 1814. It was not until 1879, however, that certain European investigators, through clinical and anatomic research, proved the affliction to be a malignant tumor of the lungs.

On the Bohemian side of the Erz Mountains in Czechoslovakia, about 30 kilometers south and east of Schneeberg, is Jachymov. This small mining town of about 8,000 inhabitants has been world famous as a source of radium from the beginning of the present century, but the history of the mines dates from the 1500's. Early in 1516, rich veins of silver were found in the Jachymov area. Exploitation was then begun but owing to the wasteful methods of mining at that time, the veins were almost exhausted by the end of the 16th century. Later, these mines were exploited for cobalt, nickel, bismuth, and arsenic. In the second half of the 19th century the exploitation began of uranium ore, found chiefly in the form of pitchblende. After Madame Curie's discovery of radium, the pitchblende in the Jachymov mines was processed for radium.

In Jachymov, as in Schneeberg, there has been a high mortality among the miners from pulmonary diseases, notably lung cancer. The similarity between the diseases developed by the miners in these two mining areas was not definitely established until about 1926. Environmental studies have shown that both mines have rather high concentrations of radon because of the presence of radioactive ores.

The causative agent for the lung cancers in these two mining areas has been controversial for a number of years. The etiological agent has been variously attributed to be cobalt, nickel, or arsenic. Others have expressed the view that radon and its decay products are responsible for the cancer of the lungs. It is probable, however, that no single agent can be blamed for this high incidence but a number of combined effects of environmental factors which are difficult to evaluate.

Information available in the medical literature of this country indicates there was an attack rate of about 1 percent per year of lung carcinoma among the miners working in these mines. It is also reported that 50 to 70 percent of all the deaths of the workers in these mines were due to a primary cancer of the respiratory system. This information was the only material available which indicated the health hazards associated with uranium mining. It must be pointed out, however, that this disease usually has developed only after an average exposure of seventeen years. Moreover, in any attempt to use these findings as a guide, cognizance must be taken of the fact that, in contrast to European practices, American operations are more intermittent. According to the Atomic Energy Commission, generally only one shift is employed, and the mines are not worked on a round-the-clock basis. Consequently, workers are not exposed immediately following the blasting, when dust and radon concentrations are generally highest.
As chronic irradiation per se represents a health hazard regardless of whether or not it induces cancer, all necessary steps have to be taken to reduce this hazard to a practical minimum, since the radon concentrations found in unventilated American mines are comparable to the concentrations found in the Schneeberg and Jachymov mines.

Sufficient information has been obtained in this study to indicate that radon and its decay products can be reduced to a minimum by the provision of adequate and effective ventilation.

III

RADON, ITS BIOLOGICAL AND PHYSICAL PROPERTIES

Uranium ores contain uranium plus all the other members of the radioactive family, of which uranium is the parent. Included in this list is radium, which is transformed into radon gas.

Radon is the heaviest gas known, being about seven times as dense as air. It is absolutely inert chemically and will react with no other material. As it is a gas, it will diffuse from the rocks or be released by drilling and blasting operations and will become dispersed throughout the atmosphere of the mine. It is radioactive and has a half life of about four days, which means that in this period of time one-half of the radon will transmute into other radioactive elements.

The radiation hazard involved in the mining of uranium ores comes from the radioactive gas, radon, and two of its most important daughters, RaA and RaC'. All of these elements emit alpha particles which are very energetic and will damage body cells with which they interact. As radon is a gas, it is breathed in along with the air in the mine and while in the lungs will continue to decay, emitting alpha particles and producing RaA, RaB, RaC, and RaC'. The daughters of radon will also decay in the lungs, likewise emitting alpha particles besides gamma and beta. Furthermore, some of the radon enters the bloodstream. Potential hazard to the lung tissue arises mainly from the alphas from Rn, RaA, and RaC'.

Under usual mine conditions, large numbers of dust particles and water droplets are present in the atmosphere to which the solid decay products of radon will become attached. This dust will be inhaled and carried into the lungs where a portion of it will be retained and decay as outlined above, thus delivering additional radiation to the lungs. The amount of this dust-borne radioactivity that is present in mine atmospheres will depend on the ventilation, air turbulence, and probably other factors. Studies have shown that where ventilation is provided the ratio of radon decay products to radon may be as low as 2 percent of the theoretical value. The facts that the solid daughters of radon will become attached to dust and be inhaled and that the ratio of radon to its decay products is profoundly affected by ventilation are very important
in assessing the potential hazard from these elements.

All of these hazards can be effectively reduced by the proper control measures, which are outlined in Section V.

IV

SUMMARY OF MEDICAL FINDINGS

The medical and clinical laboratory examinations of workers in the uranium mining and milling industry in the Colorado Plateau were begun in the summer of 1950. At the present time, over 1,100 men have undergone physical examinations with emphasis upon occupational history, chest roentgenograms, urine analyses, and blood studies, which include erythrocyte counts, total and differential leukocyte counts, hemoglobin estimations, and hematocrit values. In addition, a selected group of approximately 200 miners and millers was examined for atypical blood forms by using a peroxidase staining technique on blood smears.

At this time, no clear-cut etiologic or pathologic patterns have been uncovered among the workers examined. Since the majority of the workers has been exposed for a period less than three years, this observation is not entirely surprising. It does, however, point to the need for repeating the medical studies at frequent intervals. At the present time, therefore, it is planned to reexamine these workers periodically, using the present medical findings as a base line.

In addition, it is felt that a great deal of valuable information could be obtained by an epidemiologic study of persons who were employed in the uranium mines and mills before 1950. At this time, we have not had opportunity to examine a sufficient number of former uranium miners to determine whether or not there has been an excess of lung cancer among them.

An epidemiologic investigator has been assigned to the project to obtain as much information as possible regarding the health status of those persons who were employed in the industry prior to 1950. He is accomplishing this task by obtaining information from such sources as the following: private physicians, referred persons, death certificates, hospital records, industrial commission records, and plant medical and personnel department records. When a relationship between illness and occupation is suspected, arrangements will be made for detailed clinical studies.

The data of the 1950 and 1951 examinations made in the field have been tabulated. Some of the results are presented on the next page.
Duration of Exposure

Among the total of 913 white miners and millers studied, the following percentage distribution of exposure-durations was found to exist:

<table>
<thead>
<tr>
<th>Exposure-Duration</th>
<th>Percent of Total Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 6 months</td>
<td>23.3%</td>
</tr>
<tr>
<td>6 months to 1 year</td>
<td>14.4%</td>
</tr>
<tr>
<td>1 to 3 years</td>
<td>31.4%</td>
</tr>
<tr>
<td>3 to 5 years</td>
<td>12.4%</td>
</tr>
<tr>
<td>5 to 10 years</td>
<td>12.7%</td>
</tr>
<tr>
<td>10 years plus</td>
<td>5.8%</td>
</tr>
</tbody>
</table>

Thus, approximately 30 percent of the workers selected have been exposed for a period of three or more years, but within the next 18 months this percentage will rise to approximately 60 percent, provided the turnover of workers does not reach outstanding proportions.

Medical History

Analysis of the medical histories of these individuals showed a predominance of respiratory infections, including pneumonia and sinus infection. There was a predominance of conjunctivitis at the time the physical examinations were performed.

Several cases of illness which were encountered among mill workers were attributed to long-term exposures to relatively low concentrations of vanadium compounds.

Dental Findings

A number of workers in the vanadium processing plant were observed to have a green coating of the tongue and teeth. Workers in the area of the uranium leaching process were observed to have a yellow coating of the tongue and teeth. The incidence of dental caries did not differ from that which is observed in the general area. The edentulous persons studied were slightly younger than those previously studied in other parts of the country.

Urine Analyses

Urine analyses have failed to show any significant clinical findings.

Blood Studies

In 1950, approximately 646 determinations were completed on all of the workers examined. In 1951, all of the workers received the same examination with the exception that erythrocyte counts were done on one out of every four persons. Analysis of the blood findings shows no significant
abnormalities as far as the red cell count, leukocyte counts, hemoglobin determination, and hematocrit are concerned.

Lungs

In 1950, 13.8 percent of the white miners and 26.5 percent of the white millers showed more than usual pulmonary fibrosis, as compared to 7.5 percent in a control group. In the same year, 20 percent of the Indian millers and 13.2 percent of the Indian miners showed more than usual pulmonary fibrosis, as against none in the controls. Such a finding would indicate a tendency on the part of these individuals to develop silicosis from their exposure. These figures do not infer that the pulmonary fibrosis is occurring because of contact with uranium. It is much more plausible that past exposures to hard rock mining, as well as possible current exposures, are the real cause of this fibrosis. The statement "more than usual pulmonary fibrosis" does not always mean silicosis, but could be one of the early signs of silicosis. Approximately ten cases of definite silicosis have already been determined among the examined workers in 1951.

V

SUMMARY OF ENVIRONMENTAL FINDINGS

During the 1950 and 1951 seasons, fifty mines and eight sampling and processing mills were thoroughly studied in order to determine the toxic materials present and the degree of the workers' exposures. Obviously, individual plant findings cannot be reported in this communication, but the discussion contained herein is, in general, applicable to all milling or mining properties. The investigators have attempted to apprise each company of findings pertaining to its properties.

Mines

Radon and its decay products. -- Analysis of a statistically valid number of samples for radon and its short-lived daughters has indicated that the concentration of these radioactive substances has been too high for safe operation over an extended period, except in those locations where adequate ventilation is provided. The median level of radon concentrations in the mines of the Colorado Plateau is above the median levels reported in the European mines, where a high incidence of illness was found in the workers. It must be emphasized again, however, that strict comparison cannot be made between the American and European situations.

A value of 100 micromicrocuries of RaA and RaC per liter of air* was derived after due consideration of expert opinion and by interpolation of data from other radioactive doses known to produce biological

* $3.7 \times 10^{10}$ atomic disintegrations/second = 1 curie
damage. It is believed that the factor of safety in this value of 100 micromicrocuries, as measured by a method to be presented in Section VI, is sufficiently great to prevent damage to the lung tissue in the normal healthy worker. Experiments conducted by this Division indicate that the mines should have no difficulty in reducing the concentration of RaA and RaC' in the mine environment to this suggested value by accepted mine ventilation methods. This value is being offered as an operating standard until such time as a level for total alpha radiation is established by the National Committee on Radiation Protection.

It must be expressly understood that the value of 100 μμc/l** is being suggested without sufficient knowledge on which to base a scientific value and that the Division of Occupational Health reserves the right to re-interpret this value as scientific information is accumulated and when a value is announced by the National Committee on Radiation Protection. Prior studies of environmental hazards in other industries have not had occasion to develop maximum allowable concentration values for RaA and RaC'. The uranium mining and milling industry is the first one in this country in which large numbers of people have been exposed to this contaminant under such conditions that it could not be readily controlled.

The Division of Occupational Health and the Atomic Energy Commission are presently engaged in the initial phase of an experimental mine ventilation project. When this project is completed, a report of the findings will be issued to the operating companies. Pending the completion of this investigation, the mining companies are urged to immediately install ventilation systems according to standard practices, incorporating the suggestions contained in Section VI of this report.

Dust control is also of great importance in the suppression of RaA and RaC', as the dust particle is a means of attaching the radioactive nuclei to large particles in the atmosphere. Continued emphasis should be placed on wet drilling and the wetting of muck piles. Experiments are in order to determine the effectiveness of wetting agents in the suppression of dust. However, the operators are warned against the use of mine water for wet drilling purposes. It has been found that some mine waters are very high in dissolved radon and that their use constitutes another source of radon in the working atmosphere.

Silica dust.--Most of the uranium encountered in this study has been found in high free silica ore bodies. The free silica content of rafter dust and ore samples has ranged from 40-70 percent. Consequently, the development of silicosis by the miner is a possibility unless adequate dust control measures are used. Several cases of silicosis were detected in the medical study, but all cases had a previous occupational history in hard rock mining. Dust control in the mines has been fairly good, due to

** Micromicrocuries/liter of air
the widespread use of wet drilling and because many of the mines are so-called wet mines. Dust concentrations have ranged from 5-20 mppcf (million particles per cubic foot). It is believed that, in view of our present knowledge regarding the development of pneumoconiosis, the silicosis problem in the mines is not acute. The aforementioned range is within the legal limits of most of the States concerned. However, the importance of reducing dust concentrations to a minimum as an adjunct to controlling airborne radioactive materials is again emphasized. Those companies making their own dust counts may experience some difficulty in counting when standard techniques are used. The settling characteristics of the dust are markedly different from those of ordinary mine dust, possibly because of electrostatic charges on the dust particle. Additional information on this subject may be obtained from the Salt Lake City office by persons interested in dust evaluation.

External gamma radiation.--The matter of external radiation received by the miners has been given serious consideration by the study team. Measurements of gamma radiation have been made, using survey meters for area monitoring and pencil dosimeters for personnel monitoring. The results, however, have been erratic. The meaning of the values obtained is obscure, because a number of problems exists in the mines which interfere with radiation measurement. For example, radioactive dust will deposit on any surface and thus concentrate on survey meters and dosimeters. As a result, the instrument readings are primarily functions of the surface of the instrument and the concentration of radioactive dust and not a function of the gamma field produced by the ore bodies. Radioactive dust is also concentrated on the workers' clothes and thus increases the workers' total apparent radiation dose. The problem of measuring external radiation requires considerable study, but this inquiry has been deferred until other more acute problems have been solved. It is strongly recommended that the workers take daily baths (preferably showers) using soap freely, and that a frequent change of work clothing is desirable to minimize skin contact with the radioactive dust.

Internal radiation and chronic metal poisoning.--The levels of atmospheric uranium and vanadium found in the mine atmosphere do not appear to be sufficiently high to produce chronic uranium or vanadium poisoning. Urine samples were taken from all miners examined. The urinary uranium and vanadium levels were of a low order of magnitude.

Internal radiation resulting from the inhalation and absorption of radioactive compounds has been recognized as a potential health hazard because some of the members of the uranium series are bone seekers. This hazard has not been evaluated in the present situation but an investigation is planned. Dust control and ventilation will reduce any possible hazard connected with internal radiation, as well as hazards from chronic metal poisoning.
Mills

Since the process for the separation and isolation of uranium and vanadium is different in each mill, it is impossible to generalize the findings in this report, as was done with the mines, except in a few operations which are common to all plants. In general, it may be said that there are no health hazards in the mills which cannot be controlled by accepted industrial hygiene methods.

Radon and its short-lived decay products are not usual problems in the milling plant, due to the large volume available for dilution and the open-type construction which is, in general, used throughout the industry.

Dust control at the crushing operation has been found to range from fair to poor. The control of dust at this operation can be accomplished by standard engineering methods, but the installation should be designed by competent and skilled persons. Standards set by the State for silicosis control, using the ore of highest free silica content (70 percent), should be used as a guide in determining the effectiveness of dust control systems. This value (5-20 mppcf) should also control other health hazards associated with the dust. Since the radon has not been confined at this operation, the decay products have not had the opportunity to grow into equilibrium. Until adequate dust control has been established at this operation, the workers should be required to wear approved dust respirators. Daily baths and frequent changes of clothing by the workers in this area are also indicated.

Relatively high concentrations of uranium and vanadium fume were found around the fusion furnaces. In practically all plants the workers in this area were found to be suffering from a chronic irritation of the upper respiratory tract, apparently resulting from exposure to vanadium fume. It was also in this area that the green throats referred to in the medical summary were found. Several cases of a transitory illness were observed by the physicians among workers welding or cutting vanadium-coated pipes and metals.

Since the fusion operation is different in each plant, it is impossible to make specific recommendations applicable to each establishment. In general, it may be said that all fusion furnaces should be constructed so as to prevent fume leakage. Local exhaust ventilation should be provided at the transfer point (from furnace to casting wheel) and at the bagging operation. The workers should be provided with fume respirators for emergency and temporary exposures to vanadium and uranium fumes.

Portable exhaust blowers should be located in the fusion area and used by maintenance workers whenever it is necessary to cut or weld metal coated with uranium or vanadium.
Good personal hygiene should be practiced by the workers in the fusion area. This should include daily baths and freshly-laundered work clothes each day.

This report deals only with certain specific hazards in the mill. Exposures to other health hazards, such as acids, alkalis, certain gases, and other agents, were also noted, however. Each mill should therefore consider the advisability of a general industrial hygiene survey by the State industrial hygiene agency or other competent authority.

VI
DISCUSSION OF CONTROL MEASURES

Ventilation of Uranium Mines

The essential requisites for ventilation of uranium mines are the same as those in any siliceous ore mine. These requisites are: planned methods of mine ventilation to provide each work place with an adequate amount of fresh air; wet drilling where practicable; the rapid removal of contaminated air from the workings; and common sense dust control practices.

For operations in rock, emphasis is usually placed on wet drilling, copious use of water to spray down the surface of the work place and muck pile during loading, and forced ventilation to the work face.

The basic health problem associated with uranium mining is not only to suppress the siliceous dusts but also to lower excessively high concentrations of radon and its short-lived daughters. Dust concentrations in these mines are of even greater physiological significance as compared to those in ordinary hard rock mining, since the inspired dust is contaminated with radioactive materials. From the viewpoint of silicosis production, the dust concentration in most uranium mines is within accepted limits. This fact may be explained by the lack of activity in the mines, as they are usually small and generally only one face is worked. Wet drilling is generally practiced, and the mines are usually abandoned overnight to allow powder smoke and dust to be cleared out.

During the course of this study, the ventilation systems of a number of mines have been investigated and, based upon this experience, certain modifications to standard ventilation practice are offered in this report. It is believed that compliance with standard practice and these modifications will result in the lowering of the concentration of RaA plus RaC' to the recommended level of 100 micromicrocuries per liter in practically all mines.

In uranium mining, it appears more practicable to place the mine under positive pressure rather than under negative pressure. This would have several advantages, namely:

1. Churn drill holes from a point close to the breast of development
drifts and stopes are becoming more in evidence in the uranium mines. With the mine under positive pressure, radon would be forced from the working area through churn drill holes without distribution throughout the mines.

2. Positive mine pressure would tend to hold the radon in worked-out areas or force it from the mine through surface openings.

3. Although quite theoretical, it may be that positive mine pressure may tend to hold the radon in the fissures and rock openings of newly developed areas. The radon would tend to diffuse out of these areas when the fan is shut off at night (if such be the case), but would subsequently be expelled from these areas 30 or 40 minutes after the ventilation system is turned on.

With regard to unused workings, it is more desirable to close them off to reduce air contamination and ventilation requirements.

A number of experiments have been performed in uranium mines in order to show the effectiveness of ventilation, and several examples are presented:

1. This mine had two levels. The first level is reached by incline from the surface, and the two levels are connected by means of a second incline. At the time of the ventilation study of this mine, there was approximately 2,800 feet of 8' x 10' drift or tunnel. A 3,000 cfm* fan forced air through a 10" churn drill hole to the lowest level. This air was exhausted to the upper level by way of the incline, providing an air velocity through the drift and incline of 37 fpm.**

Approximately 7,000 cfm of fresh air moved down the main incline to the upper level, mixed with the 300 cfm rising from the lower level, and exhausted from the upper level through a 4' x 6' ventilation raise in which 10,000 cfm exhaust fan had been installed.

Samples of radon decay products were taken at the foot of each incline. Initial samples were taken when the fans had been inoperative for a period of 14-30 hours. The fans were then turned on and series samples taken over a period of time to observe the effectiveness of ventilation in reducing the concentration of RaA and RaC'. The table below is a tabulation of these data:

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Radon Decay Products</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot # 1 incline</td>
<td>7860 µmc/l</td>
<td>Fans off 20 hrs.</td>
</tr>
<tr>
<td>Foot # 1 incline</td>
<td>4720 µmc/l</td>
<td>Fans off 30 hrs.***</td>
</tr>
<tr>
<td>Foot # 1 incline</td>
<td>Less than 10</td>
<td>Fans off 4 hrs.</td>
</tr>
<tr>
<td>Foot # 2 incline</td>
<td>5370 µmc/l</td>
<td>Fans off 20 hrs.</td>
</tr>
<tr>
<td>Foot # 2 incline</td>
<td>5260 µmc/l</td>
<td>Fans off 30 hrs.***</td>
</tr>
<tr>
<td>Foot # 2 incline</td>
<td>Less than 10</td>
<td>Fans on 4 hrs.</td>
</tr>
</tbody>
</table>

* Cubic feet per minute
** Linear feet per minute
*** This decrease was caused by the overnight inflow of cold outside air
2. Another mine consisted of two separate workings in the same ore body. Both workings are reached by incline--Incline #1 and Incline #2. Incline #1 was provided only natural ventilation, and poor air movement was observed. Incline #2 was under positive pressure from a 2,000 cfm fan which provided 3 to 6 air changes throughout the workings each hour. The concentration of RaA and RaC' in Incline #1 was in the magnitude of 10,000 μc/l, while the concentration in Incline #2 was 160.

Other examples of ventilation practices are available, but it appears that these two examples serve to indicate what can be accomplished in the reduction of airborne radioactive materials by supplying even small amounts of air to the working area. Pending the completion of the demonstration mine ventilation project being carried on by the Public Health Service and the Atomic Energy Commission, the following general rules may be applied in establishing ventilation requirements for uranium mines:

1. Although each uranium mine will present a special problem in ventilation because of such factors as the grade of ore, amount of radon carried in by ground water, and exposed ore bodies, it is probable that 2,500 cfm is a minimum amount of ventilation required for a small mine.

2. Each pair of men working in a raise, stope, or dead end drift should be supplied 1,000 cfm or more from a tube outlet located within 30 feet of the breast.

3. A supply of not less than 2,000 cfm of fresh air should be supplied to the breast of an 8' x 10' drift.

4. In drifts of large cross section, the quantity of air supply should be calculated to produce a velocity of air flow of not less than 30 fpm.

5. The ventilation system should be turned on at least 40 minutes before workers enter the mine.

6. Natural ventilation of uranium mines should be fully utilized but cannot be relied upon as a suitable means of removing contaminants from the working area.

Collection and Measurement of Radon Decay Products

The success of any control program for radon and its short-lived daughters will depend upon the ability of each mine to make its own measurements. Frequent measurements should be made in the haulageway and daily measurements at the working face. In view of the fact that many workers may spend most of their working lives in uranium mines, it is so important that the suggested level of 100 μc/l be maintained in the working environment that industry should not depend on infrequent visits from State or governmental agencies for control work. These agencies should be depended upon only for consultation visits and emergency work. It is noteworthy,
also, that transport workers engaged in conveying both the ore from the mines and the more refined product from the mills are not subject to significant exposures.

With these facts in mind, a field method has been developed for the measurements of RaA and RaC', which is relatively simple and may be used by the mines for control work. This method consists essentially of the following steps:

1. Air is drawn through a one-inch diameter circle of Whatman 1 filter paper contained in a special adapter* at a measured rate (1L-23 liters per minute) by a hand-cranked pump** for either a 5- or 10-minute period. In order to simplify calculation, tables have been prepared for these two sampling intervals.

2. The filter paper is then removed from the mine and the alpha activity on the paper is measured by a field instrument (the Juno*** is a satisfactory instrument for this purpose). This instrument needs to be calibrated against a laboratory counter so that the scale may be read in alpha disintegrations per minute (dpm). Companies purchasing the instrument should send it to the Salt Lake City office for calibration. The instrument will be returned with a chart converting scale reading to alpha disintegrations per minute, a radioactive standard to check the calibration of the instrument, and a correction curve. In order to prevent contamination, this instrument should never be taken into the mines.

3. The activity (dpm) obtained by reading the instrument must be converted to time zero, which is obtained from the correction curve (see sample calculation below). This value is substituted in one of the following equations:

\[
\text{ppc/l of RaA and RaC'} = \frac{0.12 \text{ (dpm)}}{V} \quad \text{for 5 minute sample}
\]

\[
\text{ppc/l of RaA and RaC'} = \frac{0.066 \text{ (dpm)}}{V} \quad \text{for 10 minute sample}
\]

Where dpm = alpha disintegrations per minute at time zero
V = sampling rate in liters/minute

The following is an example of the method:

A sample was taken from 10:03 - 10:13 at a sampling rate of 18.5 liters per minute. The filter paper was read in a Juno instrument at 10:15, giving a reading of 26 x 100. From the calibration chart, alpha

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* Blueprint of adapter available on request to Salt Lake City office.
** The only known source of a satisfactory hand-operated pump is Mr. Lester Roberts, 316 Pennsylvania Street, Denver, Colorado.
*** This instrument is available from Technical Associates, 3730 San Fernando Road, Glendale 4, California. Cat. No. SRJ-1.
disintegrations per minute = 640,000. The correction factor (from a chart to be supplied with instrument calibration) for 32 minutes (10:45 - 10:13) is 1.8; so that the alpha activity at time zero (10:13) was 640,000 x 1.8 or 1,152,000. Substituting this value in the 10-minute formula above, we obtain 0.066 x 1,152,000 = 7100 µmc/1 of radon decay products.

In order to assist the mining companies in instituting this method of measurement, technical consultation is available by request to the Salt Lake City office. Each set of equipment for these measurements will cost approximately $100.

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VII
RECOMMENDATIONS

Mines

1. Adequate ventilation should be supplied to mines so that the concentration of RaA plus RaC' will not exceed 100 µmc/l at any work location.

2. Wet drilling, wetting of muck pile, and other dust suppressive measures should be practiced to reduce the atmospheric dust concentration to a minimum value.

3. Mine water should not be used for wet drilling purposes unless the water has been certified by a competent authority to be safe for this purpose.

4. Approved dust respirators should be worn by the mine workers until satisfactory ventilation has been provided in the mine.

5. The workers should practice good personal hygiene, including daily showers and frequent change of work clothes. Eating and storage of food in the mine should not be permitted.

6. Pre-employment and periodic medical examinations should be done on all workers. The medical studies should include detailed occupational and medical histories, thorough physical examinations (including skin examinations), laboratory analyses of blood and urine, and chest X-rays. It would be desirable that the periodic examinations be performed annually on every worker.
1. Effective dust control systems should be applied to the crushing and screening operations.

2. Dust and fume control systems should be used in the fusion and bagging operations at all points where uranium and vanadium dust or fume are liberated.

3. Local exhaust ventilation should be available whenever objects coated with vanadium or uranium are welded or flame cut.

4. Fume or dust respirators should be available to all workers who are exposed to dust or fume until such time as the exposures are controlled by engineering methods. Respirators should be available at all times for emergency or temporary exposures.

5. Good personal hygiene should be practiced by all workers. Daily baths and daily change of work clothes are recommended for those persons employed in the crushing and screening, and the fusion and bagging operations. Separate lunch rooms away from contaminated areas should be provided and used by the workers. No food should be eaten or stored in the production area.

6. Pre-placement and periodic medical examinations should be performed on all workers. The medical studies should include detailed occupational and medical histories; thorough physical examinations, including dermatological examination; laboratory analyses of blood and urine; and chest X-rays. It would be desirable that the periodic examinations be performed annually on every employee.

REFERENCES


