A79-V V-E-27

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

a/b

DATE: FEB 13 1985

SUBJECT: Submittal to Docket A-79-11

FROM: Criteria & Standards Division (ANR-460) Charles T. Robbins

TO: Central Docket Section (LE-130)

Attached for submittal to Docket A-79-11 are the following documents. We have retained copies of each for our files.

a. Letter from Quivira Mining Co to Larry Boggs, American Mining Congress dated January 28, 1985 subject Radon Emission Standard.

b. Letter from Homestake Mining Co to Larry Boggs, American Mining Congress dated January 28, 1985 with enclosures A, B, C, D, E pertaining to underground uranium mine radon-222 emission standard.

Enclosure A. Control of Radon Daughters in an Underground Mining Operation by Langan W. Swent 1984.

Enclosure B. Mine Ventilation and Air Conditioning by Howard L. Hartman.

Enclosure C. SME Mining Engineering Handbook Vol 1 by Arthur B. Cummins, 1973.

Enclosure D. Controlling Employee Exposure to Alpha Radiation in Underground Uranium Mines, Vol 2 U.S. Bureau of Mines

Enclosure E. Mine Engineering and Ventilation Problems Unique to the Control of Radon Daughters MESA Informational Report 1974

A-79-11
~~I-E-4~~

(a)

QUIVIRA MINING COMPANY

POST OFFICE BOX 218 • GRANTS, NEW MEXICO 87020

January 28, 1985

Larry Boggs
American Mining Congress
1920 N. Street N.W. - Suite 300
Washington, D.C. 20036

Re: Radon Emission Standards

Dear Mr. Boggs:

The following two maps indicate the active and inactive areas of two operating uranium mines. The areas hilighted in red are the inactive areas, blue are active mining areas.

As shown on both mine maps, approximately 95% and over are inactive areas. Most of these inactive areas have been isolated from active mining areas by bulkheading the entrance to the haulages (travelway) or bulkheading the raise (access to stope level working area). In either case, extensive use of bulkheading is performed on stope level to redirect air flow and or prevent radiation from entering fresh air supplies. The bulkheads shown on the map represent approximately less than 10% of all bulkheads used in each mine.

Sincerely,

QUIVIRA MINING COMPANY

Bill Ferdinand

Bill Ferdinand
Ventilation Engineer

ms

A79-4
KEY (6)

RECEIVED
JAN 28 1985

HOMESTAKE MINING COMPANY
P.O. BOX 98
GRANTS, NEW MEXICO
87020

January 25, 1985

Larry Boggs
American Mining Congress
1920 N. Street N.W. - Suite 300
Washington, D.C. 20036

Re: Radon Emission Standards

Dear Mr. Boggs:

Please find enclosed the following EPA requested materials for inclusion in your package to be sent to the EPA for their use in developing their underground uranium mine radon emission standard:

1) Proposed standard and definitions
   A. Bulkhead definition includes a design criteria of 5 inches water pressure drop to satisfy EPA concern of bulkhead structural reliability.

2) Maps of two mines, one (Sec. 13) was operational for 4 years and the other (Sec. 23) has operated for 27 years, showing fresh air routes, exhaust air routes and bulkheads (note - Section 23 map identifies approximately 20 to 25% of the bulkheads existing due to the scale of the map)

3) Map showing active versus inactive working areas (note - inactive working areas constitutes in excess of 96% of the mine area)

4) Excerpts from literature which may help EPA understand ventilation control in underground uranium mines.

   A. Control of Radon Daughters in an Underground Mining Operation, Langan W. Swent, 1984.

   B. Mine Ventilation and Air Conditioning, Howard L. Hartman

   C. SME Mining Engineering Handbook, Vol. I, Arthur B. Cummins, 1973

   D. Controlling Employee Exposure to Alpha Radiation in Underground Uranium Mines, Vol. 2, U.S. Bureau of Mines.

   E. Mine Engineering and Ventilation Problems Unique to the Control of Radon Daughters, MESA Informational Report / 1974.

The proposed standard and definitations are a compilation of the comments received from Atlas, UMETCO, Quivera and Homestake. Additional qualifiers or exceptions as noted in the Atlas/UMETCO comments may be warranted.

If you have any questions or comments concerning these materials, please do not hesitate to contact me.

Very truly yours,

HOMESTAKE MINING COMPANY - GRANTS

Edward E. Kennedy

Edward E. Kennedy
Director or Environmental Affairs

EEK/bgl

Copies of Proposed Standard and Definitions Only to:

D.B. Crouch
J.M. Parker
F.R. Craft
R.G. Beverly
Ed Still
J.E. Cleveland
R.E. Blubaugh
A. Courtney

Proposed Standard

"Where uranium is actively mined underground, suitable bulkheads shall be installed in abandoned work areas to reduce radon emissions in such a manner that the working environment of the underground active working area is not degraded."

Definitions

Bulkhead - Any structure designed for a miniumum pressure drop of 5 inches of water which serves as a ventilation control in active mines and which can act as a barrier for the release of radon from abandoned mine workings.

Active Mines - Those mines which actively hoist earthen material.

Abandoned Mine Workings - Abandoned areas within active mines where no activity is scheduled in the forseeable future or are physically isolated from active working areas; except those areas which function as escapeways, ventilation passageways, active storage areas or areas with a de-minimus radon concentration.

IE4(b)
encl. A.

CONTROL OF RADON DAUGHTERS IN AN UNDERGROUND MINING OPERATION

BY: LANGAN V. SWENT
CONSULTANT
HOMESTAKE MINING CO.

PRESENTED AT

AMERICAN INDUSTRIAL HYGIENE CONFERENCE

MINING SESSION

IN DETROIT, MICHIGAN

ON 25 MAY, 1984

A

CONTROL OF RADON DAUGHTERS IN AN UNDERGROUND MINING OPERATION

By: Langan W. Swent
Consultant
Homestake Mining Co.

Before I get into this subject I will first give a little background information on what radon daughters are and how they come to be in undergound mines.

Radium is a radioactive element that is formed during the process of radioactive decay of uranium through several intermediate elements. Radium is widely distributed in nature in solid form and is a minor contaminant in nearly all rocks. It has a radioactive half-life of about 1612 years and decays into radon, a chemically inert, invisible and odorless noble gas like argon, neon and helium. Radon, like its parent, is however, radioactive, having a half-life of 3.8 days. Radon in turn decays to a succession of 4 radioactive solids whose half-lives are very short - ranging from a few minutes to a very small fraction of a second. The last of these 4 decays into lead-210, which has a relatively long half-life of 22 years. The 4 short lived descendants of radon are called "radon daughters". The principal harmful radioactivity of the decay of radon and its daughters is the emission of alpha particles within the human respiratory tract and lungs. If radon daughters are inhaled, the alpha particles released while the daughters are in the respiratory tract and lungs are a hazard that may cause lung cancer. Radon has a longer half life than its daughters, and because it is a gas, most of it that is inhaled is exhaled; therefore it does not have the degree of risk presented by the short-lived radon daughters. The latter are minute, highly charged particles most of which attach themselves to the respiratory tract and lung tissues and are not expelled quickly, as is radon. Most of the radon daughters inhaled remain in the respiratory tract and lungs and continue to assault the tissues with their alpha radiation.

The small amount of radium in any rock is conatantly producing radon. A small fraction of this radon escapes from the microcrystals of the rock into the voids and interstices between the individual crystals. Some of the radon atoms in the interstices decay in place while others migrate. Those that reach the surface of the rock diffuse out into the air or water bounding the rock. In a mine working, radon thus released from the rock gets into the air which it immediately begins to contaminate with radon daughter particles. These are formed as individual, highly charged airborne ions which readily attach themselves to any dust or moisture particles that are in the air or plate out on the solid rock surrounding the opening or on any objects that are in the working. Some of these dust or moisture particles are too large to be respirable, so that radon daughters which are attached to these pose no health hazard. The unattached daughters are all small enough to be respirable and generally plate out in the upper respiratory tract wherever they first impinge on tissue. The majority of lung cancers in uranium miners, are therefore, bronchogenic cancers rather than deep lung cancers. The unattached radon daughters present a much higher hazard then the attached ones. One shortcoming of sampling for radon daughters is that no way has been devised for coveniently sampling for the respirable ones. The sampling methods in use capture all the daughters, and the results only represent what workers are exposed to rather than true dose.

The principal method of controlling radon daughters is ventilation that has sufficient volume and velocity to dilute the concentration of daughters and to remove the radon before it has an opportunity to form high concentrations of radon daughters.

About thirty years ago the U.S. Public Health Service developed a unit for quantifying the amount of alpha radiation eventually given off from a liter of air by the complete decay of all the radon daughters in that liter. At the time it was thought that working in air averaging one of these units per liter would be safe, so they called this unit a "Working Level". The important thing to remember is that a Working Level (abbreviated WL) is essentially a measure of the concentration of radon daughters in air. Whenever WL measurements are taken, what is being done is to determine the concentration of radon daughters in the air at the point being sampled. Technically 1 WL is defined as any combination of the short lived radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^{5} MeV (million electron volts) of potential alpha energy.

Another term or unit frequently used is the "Working Level Month". This is simply the concentration of radon daughters (expressed in WL) multiplied by the time (expressed in months) that a person is exposed to that concentration. Mine Safety and Health Administration (MSHA) regulations specify that 173 hours of work constitute a month for this purpose. The Working Level Month (abbreviated WLM) is the basic unit of an individual's exposure. The current MSHA limit on an indivdual's occupational exposure is 4 WLM per calendar year. The current MSHA limit on the maximum concentration of radon daughters to which individuals may be exposed is 1 WL.

In August 1979 MSHA adopted a new regulation that required all active working places in areas of any mine that average higher than 0.33 WL be sampled weekly and that exposures in WLM be calculated for each employee working in those areas. Records of these exposures must be kept and periodically supplied to MSHA as well as being subject to examination and audit.

The procedure for sampling and determining the concentration of alpha radiation in the air sampled begins with taking an air sample with a standard air sampling pump and sampling head. The required amount of air (usually about 5 liters) is drawn from the air space being sampled through a clean millipore filter paper in the sampling head. Since the radon daughters are actually tiny, highly charged particles, they are caught easily on the filter paper. If the rate of emission of alpha particles from the radon daughters caught on the filter paper can be determined, the ultimate amount of alpha radiation that will be released from a liter of the air sampled can be calculated and converted into WLs. The rate of emission of alpha particles is usually determined by putting the filter paper into one of several makes of alpha radioactivity counters. The accuracy of the determination varies greatly with the type of counter used.

For some 20 years or more the Kusnetz method has been the standard method for determining radon daughter concentrations from the filter papers. It has the disadvantage that one must wait about 40 minutes, or more, between taking a sample and determining the alpha disintegrations from the filter paper in one of the counters designed to be used with the Kusnetz method. Also, the counters are easily contaminated and the results may be biased if the counters are used underground without adequate precautions. The best results are obtained by doing the determination outside the mine in a clean atmosphere.

The principal technical development in the last few years has been the perfection and use of a class of meters which determine radon daughter concentrations in an air sample in a matter of 2 or 3 minutes without any ageing period. Furthermore, this quick determination can be done right in the mine working place.

The term "Instant Working Level Meter" has been copyrighted by one of the first companies to produce this type of meter. In order to avoid possible infringement of this copyright, I will refer to this class of meters as "instant" type meters.

After the sampling has been completed the filter paper is quickly transferred to the "instant" type meter which then begins to count the alpha and beta radiation from the paper. While counting is going on the meter cannot be moved. The counting is normally completed in 1-1/2 to 2 minutes, with each final count appearing in a separate window. The sampler then records both values in a sampling record, and adds them together to get the concentration in WL of the alpha radiation from the radon daughters that were in the sample. The total elapsed time from the beginning of sampling to the recording of the results is between 5 and 6 minutes, depending on the capacity of the sampling pump.

With the 40 minute ageing period the accuracy of the Kusnetz method 1/ plus or minus 20% in the range of 1 Working Level. If the waiting period is reduced significantly, the accuracy decreases. The "instant" type meters have about 5% more error, but that is not very significant when working in the concentration range of 0.5 Working Level, or less, where most determinations today are. The benefits of the speed with which results can be obtained offset the small additional loss in accuracy.

The advent of these meters has made ventilation control, compliance with regulatory requirements, and control of individual employee exposures much easier and more consistent. The equipment costs are considerably higher than for the Kusnetz method equipment. The cost of sampling heads, filter paper, and air pumps is the same for either method, but the "instant" type meters cost about $6,500 each, vs. about $1,500 for a Kusnetz type meter.

A number of underground uranium mine operators are now using "instant" type meters and MSHA has approved their use in a number of mines. The most comprehensive use of "instant" type meters and the one on which I am best informed is that of Homestake Mining Company in its underground uranium mining in Grants, New Mexico, so I will briefly outline that program and the results.

Homestake has standardized on the MDA Scientific Inc. model 811 meter, powered by seven 1.2 volt nickel-cadmium batteries. These batteries are charged daily and have a life of about 2 years. The first of these meters was bought in 1978 and others were purchased in 1979 and 1980 until a total of 15 had been acquired. All of them are still useable, including the original 1976 one, but only 7 are now in use as a result of reduced operations at the mines, but none have been discarded. Homestake does all normal maintenance work and has developed a number of features such as switches and covers that are more durable than those provided by the manufacturer. In operation, it takes 2 minutes to take a 5 liter sample and thirty seconds or less for the transfer of the filter paper to a meter, which then requires 1-1/2 minutes to do the reading. When the sampler has recorded the readings and added them the total elapsed time is less than 5 minutes.

With the Kusnetz method the radon daughter concentration in a working place that has been sampled is not known until at least 40 minutes after the sample has been taken. By that time the sampler has gone somewhere else and may be a long distance away. If the concentration, when finally read, turns out to be too high and action is required the sampler must return to the working place or look up the shift boss or foreman. With the instant type meters the radon daughter concentration in the working place sampled is known right while the sampler is there. To take advantage of this Homestake has trained its samplers to also be ventilation technicians and has given them authority to make ventilation changes if the readings show they are needed. This can many times be done in minutes and new readings taken to check on the effect of the changes made. Thus many minor ventilation problems can be solved in as little time as a half hour, whereas with the Kusnetz method the sampler would not yet even be aware that there was a problem.

With the ability to make quick and satisfactory determinations of the radon daughter concentrations in working places, Homestake in 1979 changed from its previous practice of sampling each working place once every 2 weeks, as required by MSHA regulations up until that time, to one of sampling each working place once per day, instead of once per week as required by the new MSHA regulations.

A very comprehensive and detailed ventilation coding system has been developed. Each working place may have as many as 16 such codes to indicate where, in a large working place, such as a stope, a sample is taken and what type of work is being done at that place, such as drilling, slushing, blasting, rock bolting etc. The sampler records both the working place number and the ventilation code numbers for each sample. Each worker indicates on his or her payroll time card the amount of time spent each shift in each working place and in each ventilation code area and activity. This data is reviewed, verified and supplemented by the shift bosses before the time cards are sent to the accounting department to be entered into the company's local computer. All the data from the samplers' daily WL determinations are also entered into the computer which matches them with each employee's time and place worked record and calculates each employee's exposure for the time spent in active working places. The time employees spend in travelling to and from their work places, between work places, going to and from and having lunch, etc. is taken from time studies made in different sections of the mine for different categories of work. The travelways, haulageways, and lunchrooms are all sampled and then a calculation is made of the exposure an employee receives outside his working places. This is added to the individual's calculated work place exposure. All salaried employees, maintenance employees and persons who work only part of the time underground also turn in time sheets and exposures are calculated for them as well.

Computer printouts are produced twice a month showing each individual's exposure for the most recent exposure period and for the year to date. These are delivered to the mine staff about 5 days after the close of each exposure period. The mine staff uses these to see if any individual has exceeded 90% of the allowable annual exposure limit of 4 WLM prorated for the portion of the year that has elapsed. If an individual exceeds the 90%, the staff determines what can be done to bring the exposure down below the 90% mark during the next exposure period. Daily, hand calculated exposures are determined for each of these individuals until the person's exposure has been reduced to below the 90% threshold. Actions taken may include improvements in ventilation in the individual's working place, changing the individual's working place, work routine or type of work.

This system was started late in 1979 and is yielding good results. In December 1979, 3 individuals in a workforce of about 379 were over the 90% and were monitored; of these, 2 had to be moved to other working places to finish the month and year with no overexposures. In December 1980, 2 individuals were monitored but none were moved. In December 1981 no persons were monitored and none had to be moved. In 1982 two persons were monitored and moved. In 1983 no persons were monitored, and none were moved. No exposures in excess of the 4 WLM per year have occurred for many years.

One MSHA regulation that is a constant source of trouble for underground uranium mine operators is regulation 57.5-39 which requires that no person be exposed to radon daughter concentrations exceeding 1 WL in any active working place. Before the advent of "instant" type meters and the capability to do daily sampling, it was a common occurrence for MSHA inspectors to issue separate citations for each working place found to exceed this limit during each inspection of a mine. In addition each such citation was accompanied by an order requiring the working place to be shut down until the radon daughter concentration was reduced to below 1 WL. Each citation involved a monetary assessment and, usually, much lost time and consequent loss of production while ventilation was adjusted until the concentration was reduced, and arrangements made to advise the inspector to sample the place again. Loss of time varied from a few hours to several days, sometimes even weeks, with the attendant loss of production depending on the type of work place involved.

To minimize the number of such citations received, most operators have adopted an internal "shutdown" limit of their own, usually 0.7 to 0.8 WL. If an operator's survey finds a working place that exceeds this internal shutdown limit, the place is shut down until the concentration is reduced. This practice has reduced the number of MSHA closures and the amount of lost time and production because a self imposed shutdown is usually handled more efficiently than one imposed by an external agency.

Homestake uses a 0.7 WL internal shutdown limit. The system of daily sampling was first begun in late 1979. Before that time it was normal to receive 7 to 10 MSHA closure orders and citations per inspection per mine. Only 1 citation has been issued to these mines for exceeding the 1 WL limit since June 9, 1981. In 1979 there were an average of 33 internal closure orders per month issued in the one mine which is still operating. These closures averaged 1[illegible].8 lost workplace-hours (not man-hours) each. In the first 10 months of 1983, these figures declined to an average of 22.3 such shutdowns per month, averaging 7.7 lost workplace-hours per shutdown. It is interesting to note that not only have the total number of lost work-place hours declined but also the number of hours per closure. This adds up to a 56% reduction in the lost workplace-hours per month. The mine management was satisfied that the extra cost of doing daily sampling (MSHA regulation 57.5-37 requires only weekly sampling) with the "instant" type meters more than paid for itself in the improved operating efficiencies this strategy yielded.

The last two years have been very economically depressed ones for uranium mines. Many of them have shut down due to the low spot market price for uranium and the lack of profitable long term contracts. Homestake has shut down 3 of its 4 New Mexico uranium mines. In November of 1983 the deteriorating economic conditions forced the company to lay off 40 employees from the remaining operating mine. To improve overall productivity, the radon daughter sampling frequency was changed from once per day per working place to once every 2 days, and sometimes only once every 3 days. Every effort was made to keep employee exposures as low or lower than they had been under the daily sampling program. In the nearly 6 months that this every other day sampling program has been in effect, no adverse results have been found. In the first 4 months following the change the internal closures per month averaged 27.7 as against the previous ten month average of 22.3.

Thats enough for technical developments.

Now I'll turn to developments in the regulatory field. In April 1980 the Oil Chemical and Atomic Workers Union (OCAW) and an organization called Health Research Group filed a joint petition with MSHA requesting that the annual limit of exposure to radon daughters in underground mines be reduced from the present 4 WLM to 0.7, and that a number of industrial hygiene and medical practices be made mandatory, such as the employer providing change rooms and showers, food storage facilities and eating facilities, work clothes and laundry services to underground mine employees, paying employees for their time to change into and out of the work clothing, providing comprehensive pre-employment and annual physical examinations including chest x-rays, sputum cytologies, and pulmonary function tests, and the keeping of the medical records of such examinations for 40 years.

The conditions petitioned for would apply to all mines considered to have radon daughter hazards under the proposed lower exposure limit.

The proposed new limit of 0.7 WLM per year would be so low that it would apply to many mines other than undergound uranium mines. Since a small amount of radon daughters is present in all air and many nonuranium mines have small sources of radium or radon in their rocks, the uranium industry radiation control problem may suddenly become a problem for many other types of mines as well if this proposal is accepted. The existing annual allowable exposure limit of 4 WLM/year requires that a person who works all year underground be exposed to a maximum average concentration of 0.33 WL. The proposed new limit would reduce this to 0.058 WL. This is slightly higher than the out of doors background air concentrations in some parts of the country and is close to what a person living in a masonry building experiences. The average annual non-occupational exposure of non-uranium-mining persons in the U.S. is estimated to be between 1 and 2.5 WLM.

At present I know of only 2 U.S. non-uranium mines that have radon daughter concentrations high enough to require radiation controls and the keeping of exposure records under the 4 WLM per year limit, but under the proposed lower limit virtually all types of noncoal mines would be involved in controls and record keeping - clay mines, base metal mines, gold mines, silver mines, other metal mines, etc. Except in the case of uranium mines, the ore mineral being mined generally has little or nothing to do with releasing radon. Rather it is the gangue rock constituents that frequently carry small amounts of radium. Since radon is soluble in water, it can be brought into a mine in underground water which has flowed through nearby formations which contain small amounts of radium. A number of mines in the U.S. and Canada are contaminated with radon daughters formed from the radon released by the water these mines make.

Upon receiving the OCAW petition, MSHA requested a recommendation from NIOSH (The National Institute For Occupational Safety & Health). NIOSH quickly assembled a report reviewing the literature of epidemiological studies on miners in America and Europe who have been exposed to radon daughters, animal experimentation, and the accuracy of exposure determinations and delivered this report to MSHA along with the general conclusion that the accumulation of 120 WLM in a lifetime of work (30 years at 4 WLM/year) is too high and should be reduced. NIOSH did not, however, recommend any specific lower lifetime or annual limit. In addition, their report was not submitted to persons outside the agency with expertise in this field and who hold different views of the health risks involved at these low levels of exposure. MSHA believed that it did not have sufficient data or expertise to propose a new exposure limit, so they requested NIOSH to go into the subject in greater depth and to give MSHA a report which will recommend what action MSHA should take, and which report will have been reviewed and commented on by experts outside of NIOSH who might have contrary views.

NIOSH then organized for a more in-depth effort. The records of the US Public Health Service study of US underground uranium miners, begun in the early 1950s, were resurrected and an attempt was made to update this study. The group being studied consists of 3362 white males and 780 native american indians who were examined by the USPHS and who worked 1 month or more in a U.S. underground uranium mine or mines. The last complete formal report on this group was made in 1971. An updated mortality analysis of this group was released in 1981, but it did not contain any exposure or smoking data. The records available have only the uranium mine exposures and smoking data to 1969. It was, therefore, decided to update the exposure and smoking data. This is a major undertaking and requires more funds than NIOSH has available to use on this project, so they have made an arrangement for the National Cancer Institute to provide funds for this. NCI procedures require using an outside contractor to do the job, so a contract was let at the end of September 1983, which will allow the contractor two years to complete this updating and to submit a report. Shortly after that NIOSH will finish its own comprehensive new report on the experience of the group.

A short study is being attempted which will analyze the experience of about 685 nonsmokers (defined as men who never smoked cigarettes) in the white male study group, using the available exposure, smoking, and mortality data. Expected lung cancer deaths for comparison with the observed deaths are being calculated by a complex method that will determine expected deaths for nonsmokers. This short study is expected to be done in less than 6 months from now. At the moment the analysis seems to indicate that there is no adverse lung cancer effect on nonsmokers due to low level radon daughter exposure.

NIOSH is also subjecting the first report they submitted to MSHA to further review. Depending on the outcome of the review, it may or may not be resubmitted to MSHA.

Recently the OCAW and the Health Research Group filed suit in US District Court to require MSHA to issue a temporary emergency standard of 0.7 WLM per year. The issuance of an emergency temporary standard requires a finding by MSHA or the court that employees are exposed to a "grave danger" under the existing regulations and conditions. The American Mining Congress has intervened in the suit. MSHA has requested a prompt recommendation from NIOSH. By the time this paper is given NIOSH may have made some recommenation but unfortunately it will not be based on the results of the updated U.S. Underground Uranium Miners study since this update will not be ready for another year and a half.

At some point, MSHA may propose new regulations or modifications of the existing ones, based on the recommendations it has received from

NIOSH. If this is done, there probably will be a period for public comment on the proposals, and a public hearing may be required. To prepare for this the American Mining Congress two years ago created the Uranium Mine Health Subcommittee to follow the developments, review new data and reports, make comments, and to obtain unbiased reports and expert witnesses for any hearing that is held. Although this subcommittee reports to the AMC Uranium Policy Council, the members are quite mindful of the fact that new developments may affect mines other than uranium mines, since many of the members represent companies with both uranium and non-uranium mines.

In 1981 MSHA requested the U.S. Bureau of Mines (USBM) to study the cost to underground uranium mine operators of maintaining the present 4 WLM per year maximum exposure limit and the additional costs that would be incurred if this limit were changed to 2 WLM per year, to 1 WLM per year, and to 0.5 WLM per year. The USBM in 1982 awarded a contract to Batelle-Northwest Laboratories to do this study. As of now, a draft final report from the contractor concludes that:

1. Most mines would be unable to meet a 2 WLM/year standard under the current depressed market conditions. Three of the 14 mines included in the study ceased operation during the study because of the poor market conditions.

2. Most mines could meet a 2WLM standard if the uranium market price recovered to the plus $40/lb. of U308 range.

3. Most mines would be unable to meet a 1WLM standard even if the uranium market recovered to $40 per lb. of U308.

4. From both technical and economic standpoints, a 0.5 WLM/year limit cannot be met using forced air exclusively. Only 2, relatively new mines might be able to meet this standard.

Although it is not a U.S. regulatory agency, it is important to know that the International Commission on Radiological Protection in a report adopted in March 1981 recommended an annual limit of exposure of 4.8 WLM. The report studied two approaches to determining the annual limit. One was by making theoretical calculations of the amounts of radon daughters deposited in the respiratory tract and lung tissues and their effect. The other was by evaluating epidemiologic studies. Each analysis resulted in a range of values because of uncertainties. The range for the theoretical calculations was 4.8 to 14 WLM per year, and that of the epidemiologic studies was 1.5 to 5.5 WLM per year. The recommended value of 4.8 WLM per year was determined by selecting the average of the area of overlap of the results of the two approaches.

Figure 1 shows the decline in the average WLM to which U.S. undergound uranium miners who worked 1500 or more hours per year for one employer have been exposed from 1970 through 1982. The 4 WLM/year limit went into effect on July 1, 1971. For the period 1967-71 the limit was 12 WLM/year. Average exposures of persons who worked at least 75% of their time underground appear to have levelled off at about 1.3 WLM/year.

Figure two shows the average WLs to which U.S. underground uranium miners have been exposed. More data is available on this, so the chart shows the period 1937 through 1982. This slide shows the tremendous improvements that have been made. In the last few years the average WL seems to have levelled off at about 0.13 WL. The data for the last 12 years is from annual surveys which I have been performing for the Atomic Industrial Forum Mining and Milling Committee. MSHA and NIOSH are dubious about the accuracy of these figures. MSHA has produced estimates, based on their regular mine inspections and on a series of special radiation inspections, which indicate the average exposures to be much higher. Unfortunately the MSHA estimates included the use of concentrations determined in places where no persons were working and incorrect estimates of the length of time the work force of each mine spent underground. Also, the concentration values used are those determined by MSHA during the period of the inspection of a particular mine - usually a matter of a few days - and so do not reflect conditions throughout a whole year.

As a part of the review being done by NIOSH and MSHA of this subject it is very important that those agencies realize that the industry exposure figures are far better than their own estimates. One of the good things about the Homestake sampling, control and exposure calculation program described above is that MSHA and the New Mexico State Mine Inspector have reviewed and audited the system extensively and in depth, have found no flaws or errors in the system, and have concluded that the Homestake exposure data (which is included in the industry data) is valid. This is a step in the right direction for the mining industry.

Thank you very much for your attention.

FIGURE 1

Average Exposures of U.S. Underground Uranium Miners In Working Level Months By Years Based On Miners Who Worked Underground 1500 Hours Or More Per Year For One Employer

Source: Atomic Industrial Forum

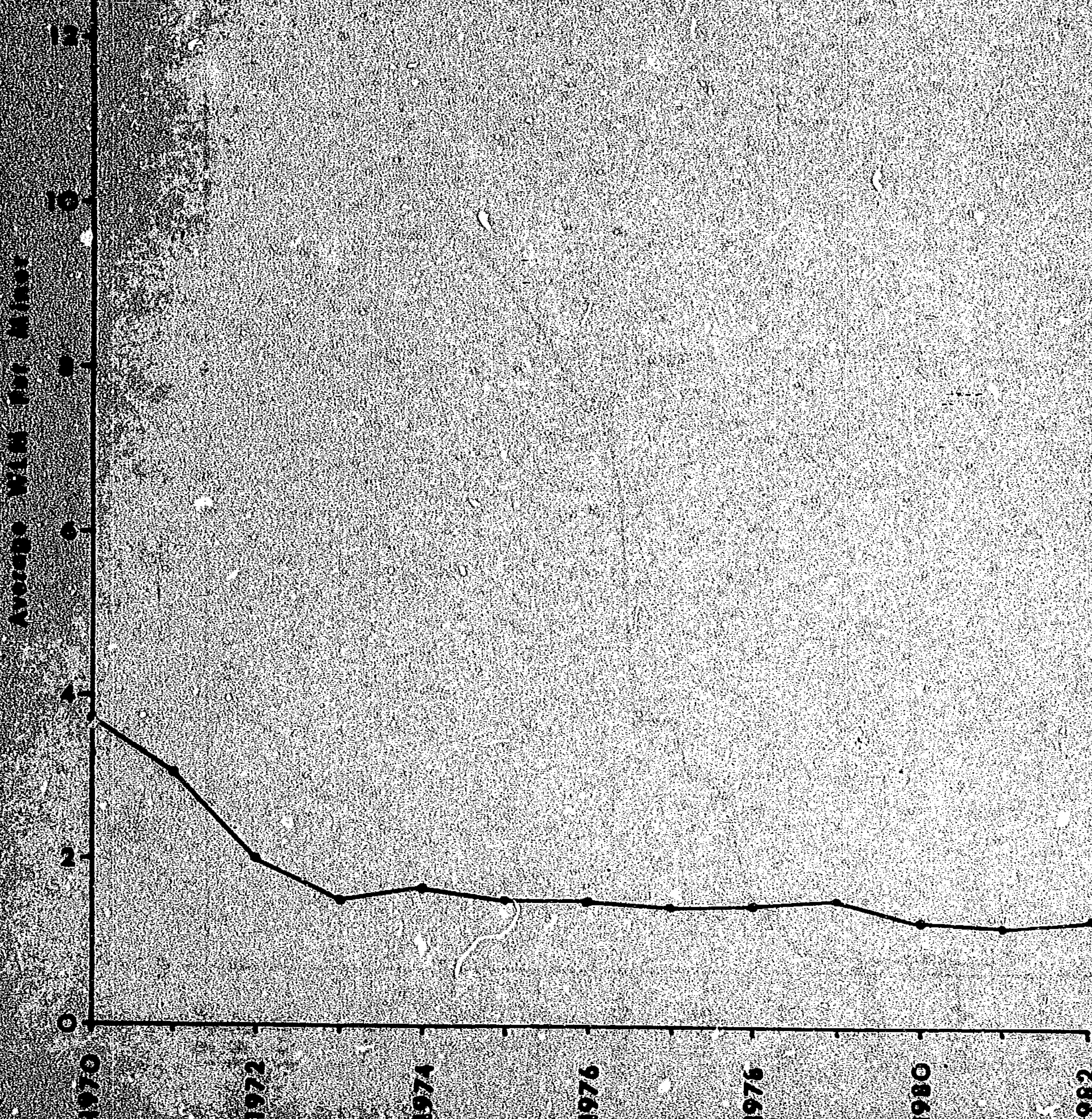
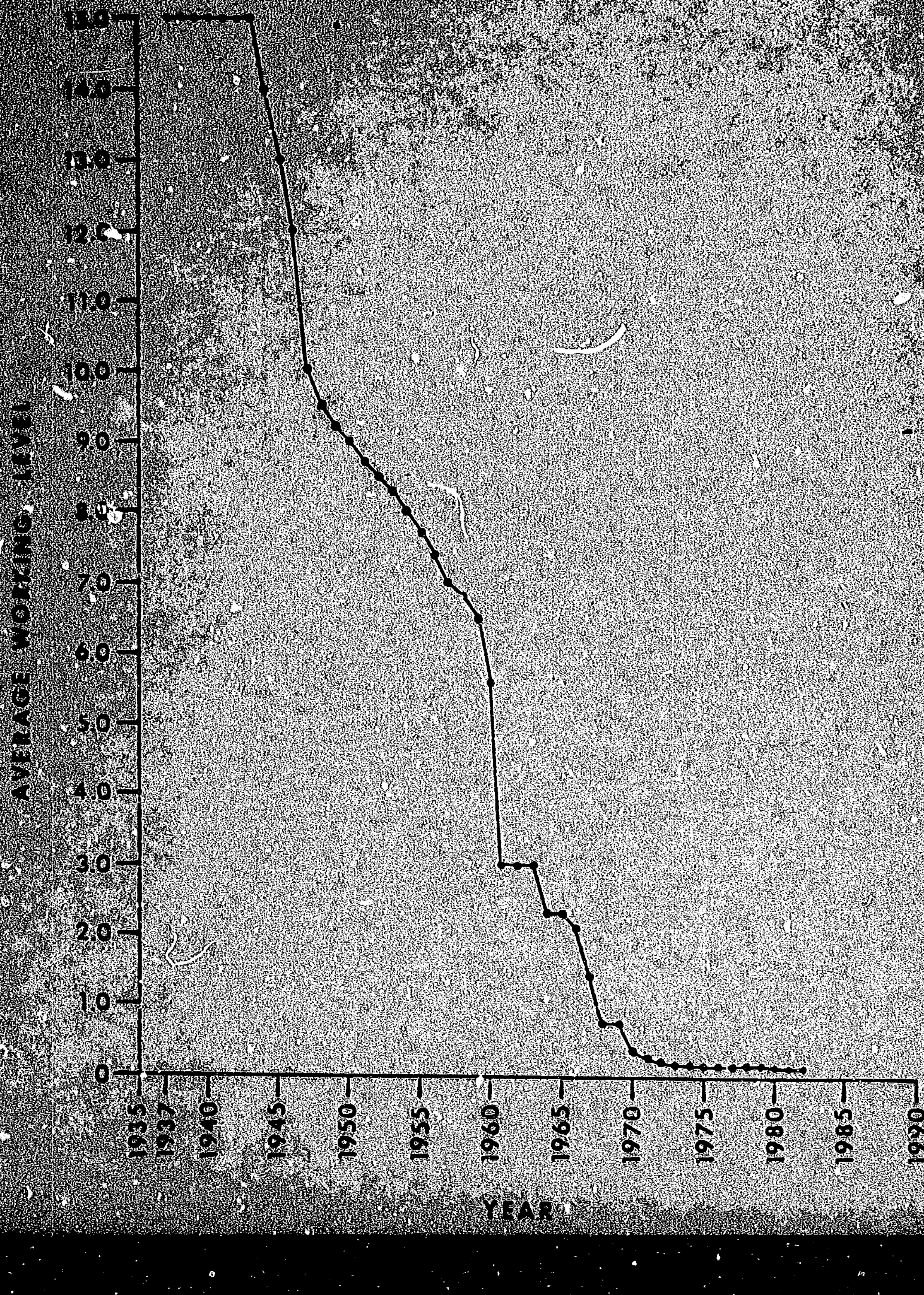


FIGURE 2

Average Concentrations to Which U.S. Underground Uranium Miners Were Exposed in Working Levels

Sources: United States Public Health Service, United States Bureau of Mines and Atomic Industrial Forum



MINE VENTILATION AND AIR CONDITIONING

HOWARD L. HARTMAN

PROFESSOR OF MINING ENGINEERING AND
HEAD, DEPARTMENT OF MINING
THE PENNSYLVANIA STATE UNIVERSITY

THE RONALD PRESS COMPANY · NEW YORK

13

MINE VENTILATION SYSTEMS

13-1. Components of the System. As previously defined (Art. 9-1), a mine ventilation system consists of the following essential components: (1) pressure source (fan), (2) connected ducts (mine openings), (3) control devices (stoppings, door, regulators, etc.). Some natural ventilation may exist in conjunction with the fan, but no further consideration will be given to systems comprised of natural ventilation alone. It will be assumed that the system is of the controlled mechanical type. The concern of this chapter is to discuss certain aspects of the ventilation system as a whole.

It should be recalled that the chief function of ventilation as an air conditioning process is quantity control, which is concerned with air movement, its direction and magnitude. Supplying air in the desired amounts to the various working places in a mine is referred to as *air distribution*. It is accomplished by adopting a ventilation method and plan suitable for the mining method to be employed in exploiting the mineral deposit; both ventilation and mining method should be selected to complement one another. A good ventilation system incorporates effective air distribution with a well-planned ventilation method and offers flexibility in meeting emergencies as well as future needs.

Effective distribution signifies that both direction and quantity of air flow are controlled. Location of pressure sources and control devices and interconnections of airways will determine direction, and intensity of source and magnitude of resistance of openings will determine quantity. In other words, means of control are afforded by modifying the pressure source and/or the mine openings. Control devices are the final component of a mine ventilation system to be introduced.

13-2. Ventilation Controls. Effective air distribution is accomplished through the installation of various control devices in mine airways. However, their use and location, while determined by ventilation needs, must always constitute minimum interference to the flow of mine traffic.

Stoppings. A stopping blocks off a mine opening to prevent flow of air. Stoppings are classified according to construction, length of service, and purpose as *temporary* or *permanent*. Temporary stoppings are constructed of tarred paper, telescoping metal sections, frame (rough), plywood, inflatable plastic, or plastic sprayed on wire mesh. They are moderately airtight and are used in active workings where changes occur rapidly in the mining and ventilation methods; they must be readily movable and are generally reusable. In place of temporary stoppings, particularly in room-and-pillar work in coal mines, curtains of brattice cloth may be used. Curtains leak badly but have the advantage of permitting the passage of personnel and are quickly installed. Stoppings not only stop the flow of air but of traffic as well, unless provided with a door. [redacted] are constructed of frame (timber), sheet metal (prefabricated sections), masonry (stone, brick, or concrete block), or gunite sprayed on wire mesh. Because their purpose is complete stoppage of air flow for an indefinite period, they must be made airtight (by taping, plastering, or caulking) and resistant to cracking from blasting concussion or ground movement. Permanent stoppings are used as fire bulkheads, to seal off abandoned workings, or in breakthroughs in room and butt entries in coal mines.

[redacted] door is essentially a stopping with a movable partition to permit pa[redacted] personnel and equipment. While a slit brattice curtain may be considered a temporary "door," all other types are of more solid construction and considered as permanent or semipermanent.

Operation. The simplest arrangement is manual operation; a self-closing feature is desirable and may be incorporated by hanging the door off center or by using a spring or weight (as a precaution in preventing doors from being left open). Mechanical operation is accomplished by a compressed air cylinder actuated by hand or electric solenoid; this is recommended for main doors. Occasionally, doors on main haulageways are made automatic by integration with a block-signal system (a photoelectric cell can also be used).

Materials. Doors are usually of frame construction, treated to make them fire retardant, and consist of one or two layers of planks, sometimes covered with a tarred paper. Sheet metal and iron doors are also used, particularly for fire doors.

Installation. Doors may be installed single or double and are hung vertically. They should be arranged to open against the normal direction of air flow but should be weighted to prevent their standing open in event of reversal of air flow. Doors are usually fitted to overlap the frame and are gasketed; since a jamb ordinarily cannot be used, a strip of rubber belting is tacked along the bottom. The frame should be built to the shape of the opening and made as leakproof as possible. If double, the doors should overlap. When the air pressure drop across the door is high (over 1 or 2 in.) and difficulty is experienced in opening it, a small door that can be opened by hand is usually cut in the main door. Otherwise, mechanical operation will have to be provided.

Use. Doors are usually installed for ventilation purposes, ordinarily serving as stoppings but acting as regulators if propped open. Emergency, Fireproof doors of metal construction are also located at strategic points for closing in event of fire or explosion to isolate the combustion area (82, pp. [illegible]). Whatever their use, care must be exercised that doors are left in the position desired.

AIR LOCK. When two doors are installed in series to prevent short-circuiting of air flow during passage of men or equipment, an air lock results. Air locks should be installed instead of single doors where interruptions of the ventilation circuit are frequent and serious or the pressure drop is high. This is particularly desirable in entries or haulageways serving also as major airways or located near them. The distance between doors should be made great enough to accommodate the longest train of cars or equipment passing. Mechanical doors are usually prevented from opening or equipped with a warning device when one door of an airlock is open and an attempt is made to open the other.

REGULATOR. A regulator is a device for creating shock loss to restrict passage of air through an airway. Regulators and their use have been discussed previously (Art. 7–4). They are usually set in doors as adjustable, sliding partitions that can be varied to the desired opening. In their simplest form, for temporary service in an untraveled part of the mine, regulators consist of doors propped partially open. When possible, regulators are located on the exhaust side of a split (in a return airway) to minimize interference with traffic.

CROSSING. A crossing is a device to permit the passing of two streams of air at an intersection without mixing. In coal mines, crossings are usually designed as (and termed) *overcasts*, while in metal mines, they are much less frequently used and are usually of the *sidecast* variety. *Undercasts* are infrequently used, because of the drainage problem, but have the advantage of not disturbing the roof. Crossings are erected to interfere with travel only in one direction, being placed across the entry or heading that is least traveled. When well constructed, resistance to air flow is increased nominally and in one direction only. A comparison of shock losses for various types of overcasts is made in Fig. 13–1. Overcasts in coal mines are of metal or masonry construction. Prefabricated, culvert-type units of corrugated steel have been used extensively. In metal mines, sidecasts are usually constructed of frame lined with tarred paper.

LINE BRATTICE. A partition placed in the opening to divide it into intake and return airways is termed a line brattice. The use of line brattices in coal mines to advance development headings and rooms beyond the last breakthrough was discussed in Art. 12–2.

VENT PIPE OR TUBING. An auxiliary fan and ventilation pipe is used to supply or remove air from the face of a working by providing an additional duct for air flow. The use of fans and vent pipe in metal and coal mining, I-E-4(b) and c

NG MEN

—The Editor

SME Mining Engineering Handbook

In Two Volumes

Volume 1

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~~the dust-control measures—immediate supervisors, miners and maintenance men—should be consulted before a design or technique is given final approval.~~

~~The implementation of a dust-control system should be complemented by a well-planned maintenance program. Initially, this will entail the education of supervisory and mining personnel in the details involved in the operation of a system or technique so that the greatest benefits may be derived from the dust-suppressive measures. Since such personnel are subject to job transfers, this educational training should be on a continuing basis.~~

~~Finally, the services of a competent ventilation engineer should be available continually to assess the effectiveness of all equipment and techniques. This is best accomplished by making monthly surveys, which include measurements of dust concentrations at all working places and accumulation of relevant data on the dust-control and ventilation systems in the mine. The analysis of this information will reveal the causes of poor air conditions and indicate where the dust-suppression measures need to be modified and/or extended.~~

16.6—VENTILATION FOR ENVIRONMENTAL CONTROL—URANIUM MINES

G. REUBEN YOURT

The main objective in providing healthful air conditions in any mine is to prevent miners from breathing harmful concentrations of airborne contaminants, such as dust, diesel and blasting gases, and methane. In uranium mines it is necessary to control airborne α radiation in addition to some or all the other contaminants previously mentioned. The conventional method of controlling airborne contaminants is tripartite:

1. Suppress their formation.
2. Confine what cannot be suppressed.
3. Dilute and remove what cannot be suppressed or confined by means of general and auxiliary ventilation.

Although this threefold approach must be applied to all contaminants in a uranium mine, only specific applications in controlling airborne radiation will be described in this section.

16.6.1—NATURE AND SOURCE OF AIRBORNE RADIATION

The ore in uranium mines contains considerably more radium than other types of rock in the earth's crust. The radium, which is a link in the uranium-family decay chain, gives off radon gas while it disintegrates, as indicated in Table 16-8.[illegible]

Radon is a chemically inert gas which diffuses in infinitesimally small amounts from the rock as, and after, it is formed by the decay of radium. Of physiological significance is the radioactive decay from radon through a series of four particulate-disintegration (daughter) products, RaA, RaB, RaC and RaC', of which RaA and RaC' are α-emitters as illustrated by Holleman[illegible] in Fig. 16-50.

During inhalation these daughter products are deposited, directly (unattached) or attached to dust, smoke or fine moisture droplets, on the walls of the bronchi or lung cells. The α-emission from an excessive deposit over a period of years may result in the development of respiratory cancer. This effect is well described by Holaday et al.[illegible] and more recently by others.[illegible]

16.6.2—RADIATION CONTROL

The control of airborne radiation in a uranium mine depends largely on the rate of emanation of radon gas from the solid and fractured walls, roof and floor and, even more so, from the broken ore on the floor. Recent research on the nature and rate of this emanation in ores with various porosities have been described by Schroeder and Evans[illegible] and by Thompkins and Cheng.[illegible] The procedures for

TABLE 16-8—The Uranium Series

Isotope	Symbol	Historical Name	Half-Life	Radiation	α Energy, Mev
Uranium 238	^{238}U	Uranium I	4.5×10^9 yr	α	
Thorium 234	^{234}Th	Uranium X_1	24.1 days	β, γ	
Protactinium 234	^{234}Pa	Uranium X_2	1.18 min	β, γ	
Uranium 234	^{234}U	Uranium II	2.50×10^5 yr	α, γ	
Thorium 230	^{230}Th	Ionium	7.6×10^4 yr	α	
Radium 226	^{226}Ra	Radium	1620 yr	α, γ	
Radon 222	^{222}Rn	Radon	3.82 days	α	5.49
Polonium 218	^{218}Po	Radium A	3.05 min	α	6.00
Lead 214	^{214}Pb	Radium B	26.8 min	β, γ	
Bismuth 214	^{214}Bi	Radium C	19.7 min	β, γ	
Polonium 214	^{214}Po	Radium C′	164×10^{-6} sec	α	7.69
Lead 210	^{210}Pb	Radium D	22.0 yr	β, γ	
Bismuth 210	^{210}Bi	Radium E	5.0 days	β	
Polonium 210	^{210}Po	Radium F	138.4 days	α	5.30
Lead 206	^{206}Pb	Radium G	Stable		

measurement and prediction of emanation which they describe enable mining engineers to design the best methods and the quantities of ventilation required to control radiation.

Considerable research done on the feasibility of depressing the emanation of radon gas from exposed rock surfaces by pressurizing the mine atmosphere has been described by Schroeder et al.[50] They found that the method is only feasible if the rock is porous and if a sink is provided to absorb the permeating gas

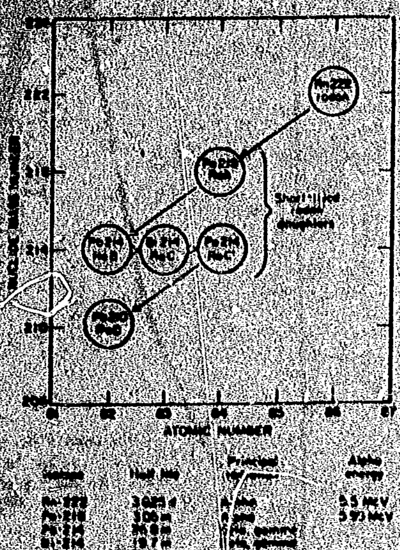

Fig. 16-50—Particulate-disintegration (daughter) products of radon, RaA, RaB, RaC and RaC′, showing RaA and RaC′ as α-emitters (*Holleman*[43]).

and air. Because of the di of permeability in most ur found appreciable applicatio

A variety of coatings ha rock surfaces in an effor be in a general use. Ra to stable lead within the

The rate of disintegratio altered, therefore the form be suppressed. Consequently and removing them from the

16.6.3—CONFINING RADIATIO

The most effective metho mined-out stoping areas, an by ventilation stoppings. It vacuum by exhaust ventilatio

As radon is partially solub to the mine atmosphere, th by diverting the water thro radiation.

16.6.4—DILUTING AND REMO

Both general and auxilia including uranium operations

General Ventilation—Briefly mine through one or more n workings, including travelway to surface through one or mo systems. In the blowing, the opening on surface or at the the fan(s) is installed at th bottom of a shaft used for a r

An ideal system preferred especially for uranium mines, to the active stoping areas by centrally on strike near or in mined-out stopes and two (o of the ore zone or sections t The fresh-air fan handles s the travelways and haulagew at the collar. The main advant

1. Fresh air can be deliv levels enabling one-pass ventil

2. Mined-out workings car tion of active workings

3. Fresh air can be made development work.

4. Pressures across doors an

Another advantage in mine will ... the stopes where

... the fresh air opening is ... sufficiently high to ... available, they should be

In mines where the top of it may be necessary for econ and air. Because of the difficulty and cost of providing such sinks and the lack of permeability in most uranium ore bodies the pressurizing method has not yet found appreciable application.

A variety of coatings have been tested to seal the pores and crevices of exposed rock surfaces in an effort to retard radon emanation but none are known to be in a general use. Retarding radon emanation would result in disintegration to stable lead within the rock and consequently reduce the hazard.

The rate of disintegration of radioactive materials such as radium cannot be altered, therefore the formation of radon gas and subsequent α-emitters cannot be suppressed. Consequently efforts must be concentrated on confining, diluting and removing them from the breathing areas of mining personnel.

16.6.3—CONFINING RADIATION

The most effective method of confining radon and radon daughters is to isolate mined-out stoping areas, and other similar openings, such as headings and raises, by ventilation stoppings. It is even more effective if such areas are kept under vacuum by exhaust ventilation.

As radon is partially soluble in water and emanates from seepages upon exposure to the mine atmosphere, the sealing of such seepages by grouting, etc., and/or by diverting the water through pipes is another effective method of confining radiation.

16.6.4—DILUTING AND REMOVING RADIATION BY VENTILATION

Both general and auxiliary ventilation are used in most underground mines, including uranium operations.

General Ventilation—Briefly, in general ventilation, air is introduced into the mine through one or more main fresh-air openings, circulated through the active workings, including travelways, haulageways and stoping areas, and then returned to surface through one or more return airways. There are several general ventilation systems. In the blowing, the main fan(s) is installed at the top of the fresh-air opening on surface or at the bottom of a shaft used as an airway. In the exhaust, the fan(s) is installed at the top of a return airway on the surface or at the bottom of a shaft used for a return airway.

An ideal system preferred by the writer and some other ventilation engineers, especially for uranium mines, involves a push-pull arrangement. Fresh air is delivered to the active stoping areas by a blowing fan(s) through a fresh-air opening located centrally on strike near or in the ore body. Contaminated air is removed through mined-out stopes and two (or more) return airways at or near the remote ends of the ore zone or sections thereof by exhaust fans, preferably located on surface. The fresh-air fan handles sufficiently more air than the exhaust fans to keep the travelways and haulageways ventilated and the main shaft slightly upcast at the collar. The main advantages for uranium mines are:

1. Fresh air can be delivered directly to the stoping area on one or more levels enabling one-pass ventilation if necessary.
2. Mined-out workings can be kept under a slight vacuum to prevent contamination of active workings.
3. Fresh air can be made readily available for stope preparation and lateral development work.
4. Pressures across doors and regulators in the ore zone are low.

Another advantage at mines using diesels for loading and haulage is that gases will not reach the stopes where the majority of miners usually work.

If the fresh-air opening is located in the ore body, air velocities should be kept sufficiently high to prevent a buildup of radiation. If footwall haulageways are available, they should be used for lateral distribution of fresh air.

In mines where the top of the ore body is over, say, 1,000 ft below surface it may be necessary for economic reasons to use one or more shafts for moving air into and/or out of the mine. In such instances main fans must be located underground because it has not been found feasible to make headframes airtight.

Air Distribution—In uranium mines it is especially important to deliver fresh air directly to the miners and then remove air containing radon as quickly as possible. This minimizes the growth and accumulation of radon-daughter products, which are many times more harmful than the radon gas. One method of achieving this objective is to effect frequent air changes in the active mine openings where men are working. If relatively high velocities are maintained in and between working places it sometimes is feasible to use air twice or even three times. The importance of this age-of-air concept and methods for circulating and predicting ventilation requirements are well described in earlier references.[4,6]

Auxiliary Ventilation—All development headings and raises in ore and also some in waste where water seepages emanate radon and all dead-end stopes must be ventilated by auxiliary fans and pipe and/or flexible tubing. The blowing system provides the best protection against radiation exposure to men working at the face, provided that the fan intake is in fresh air and the end of the pipe or tubing is kept near the workers. Sufficient air must be circulated to dilute and sweep away airborne radiation at the face and in the travelway. If there are significant emanations in a travelway that cannot be sealed or isolated, it may be necessary to remove them by a separate exhaust system with inlets at the emanations. The exhausted air should be delivered to a return-air circuit.

16.6.5—CLEANING AIR FOR RECIRCULATION

Small filters are used at a number of uranium mines to remove radon-daughter products from contaminated air. This air is suitable for ventilating individual working places provided it is delivered within a few minutes after filtration. The practice is particularly applicable in remote workings where contamination of airways is a problem.

The choice of filtering media should be made after a study of conditions, such as concentration of airborne radioactivity, dust, diesel smoke and moisture particles (or humidity). For example, following the research briefly reported by Frame,[7] and subsequently described by Washington and Kruzich,[8] a uranium mining company purchased a 40,000-cfm filter fitted with heavy-napped terylene bags. Based on experience with a test unit, this filter will remove less radioactivity than other types of fabric, some with a precoating, but will present fewer operational problems—for example, resistance due to clogging by diesel smoke, dust and moisture, and excessive maintenance.

With further improvements in the technology of filter media, more restrictive regulations regarding permissible concentrations of radioactivity and dust, and the increasing capital and operating costs of mine ventilation, the practice of cleaning mine air to permit recirculation probably will increase.

16.6.6—RESPIRATORS

Improvements in the efficiency of various types of respirators are well described in the literature. This means of protection against exposure to radon daughters in uranium mines has not received wide acceptance for strenuous work. High-efficiency conventional and battery-powered respirators have been found useful at bacterial-leaching operations in mined-out areas which are difficult to ventilate. A very light cellulose-type disposable filter with low resistance now being prepared for commercial distribution may fill the need for this means of personal protection in areas where airborne radiation cannot be adequately controlled by ventilation.

16.6.7—MONITORING AIRBORNE RADIATION

The methods used in uranium mines for measuring radon daughter products for over a decade were provided by Holaday, Kusnetz et al.[9] In 1970, the Atomic Energy Commission and several mining companies purchased working-level meters

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CONTROLLING EMPLOYEE EXPOSURE

TO ALPHA RADIATION

IN UNDERGROUND URANIUM MINES

Volume 2 of Two Volumes

(Appendixes for the use of radon-daughter control specialists)

UNITED STATES DEPARTMENT OF THE INTERIOR

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~~circuit. In practice, the ideal system is rarely obtained. In uranium mines the total air ... is often passed through a single drift, and the first split point occurs at the first working place.~~

UNDERGROUND AIR CONTROL DEVICES

Regulators

When the split system of mine ventilation is used without control, the quantity of air induced by the mine fan divides into the various mining areas according to their resistance. The volume of air entering each area varies inversely with the square root of its resistance, and areas of low resistance receive the greatest air volume while high resistance splits receive the lowest air volume. To control air distribution, an artificial resistance device is added to each low resistance split. This simple device balances split energy losses and is called a regulator.

Since efficient mine air distribution depends upon regulators, these devices should be substantially constructed. The sliding door regulator (fig. A–26) is one of the most satisfactory and most commonly used devices.

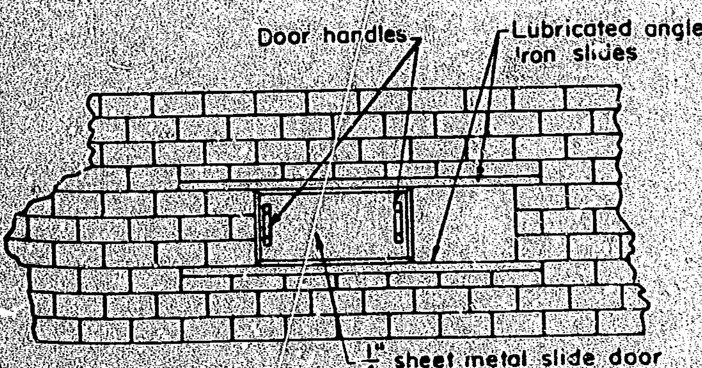

Figure A–26.—Sliding door regulator.

Stoppings

Stoppings guide airflow through the mine and prevent short circuits by blocking air travel. They are also used to seal off portions of a mine. They may be temporary or permanent, depending upon purpose and length of service. Temporary stoppings are often constructed of jute fabric, urethane-coated jute, plastic (PVC), rough lumber covered with tarpaper or plastic, or telescoping sheet metal sections. Such stoppings can be relatively airtight and are used in active workings where frequent changes in airflow may be necessary. In the vicinity of active stopes, temporary stoppings that can be opened to prevent blast damage are sometimes used.

Permanent stoppings (bulkheads) are installed to provide long-term control of airflow. In uranium mines, single wall and waste-packed double-wall frame stoppings are sometimes used. Others may be constructed of prefabricated metal channels, or masonry. Because their purpose is to control airflow for long periods, they should be sealed against the country rock and protected against ground movement. Timber or frame construction yields somewhat without failure, but leakage may become severe. Stoppings of this type should be checked periodically and sprayed with sealants as necessary. Masonry stoppings are not suitable in heaving ground without allowance being made for ground movement. This can be accomplished by using solid cement blocks and substituting a row of soft wood cushion blocks for the top course of the stopping. Telescoping metal stoppings are available that are designed to compress to approximately 50 pct of their original height without failure or excessive leakage.

In regions of highly unstable ground with lateral thrust, satisfactory stoppings may be constructed of rectangular dried wood blocks laid skin to skin without mortar. After initial placement the wood blocks absorb moisture and swell. As load increases, the blocks form a dense stopping that will compress without rupturing. When initially installed, this type of stopping should be sealed to minimize leakage.

intake airstream, equalizes pressure between abandoned areas and vents contaminated air to the return air courses.

Undercasts, return air crossings beneath the intake airways, are rarely used because maintenance is difficult.

CONTROL OF RADON GAS FLOW BY SEALANTS[6]

Radon gas can enter active workings in a uranium mine from strata and through barrier stoppings isolating inactive workings. An effective sealant reduces radon efflux by retarding gas migration in adjacent strata and by lowering the gas-flow rate due to the restrictive effect of the sealant. To be effective, the sealant must not only have a low-permeability coefficient but also completely cover and adhere to the mine strata or structural surfaces. The longer radon molecules remain in the strata or sealant, the greater their probability of decaying into particulate matter. Information on radon flow in strata has been published (*19-20*).

The permeability and adherence properties of the following nine sealants[7] were studied by the U.S. Bureau of Mines. The first five materials are known to have been used in mines. Suitability of the other four, with regard to toxicity, flammability, or cost, is not known.

1. *Asphalt Emulsion—American Minechem E-771.*—An odor-free asphalt emulsion, *reportedly* nonflammable and nontoxic. When applied, it forms a permanent, sticky, elastic film.
2. *Latex—American Minechem AL-1000.*—A water-base latex which is odor-free, *reportedly* nonflammable and nontoxic. When applied, it forms a slightly sticky, elastic film. Upon drying by water evaporation, the film is not tacky and is slightly elastic.
3. *Quaker Koat—Quaker State Oil.*—An odor-free asphalt emulsion, reportedly nonflammable and nontoxic. Upon drying by water evaporation, the film is not tacky and is slightly elastic.
4. *Sand-Cement Mixtures.*

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[6] Author cited in footnote 4.

[7] Reference to tradenames is made for identification only and does not imply endorsement by the Bureau of Mines.

5. *Urethane Foam.*—A tough cellular material produced when two liquid chemicals, a resin and an isocyanate, are mixed at a nozzle and sprayed as fine droplets onto a surface. Curing is by chemical reaction. Excessive concentrations of isocyanate vapor are toxic. Details of the urethane foams sealing were reported previously (*16-17*).

6. *American Mirachem PL-341.*—An odor-free material, reportedly nonflammable and nontoxic. When applied, it forms a sticky, elastic film. Upon drying, the film is not tacky and is slightly elastic.

7. *Plastic Roof Cement, Pure Asphalt Base—20th Century Paint Products Co.*

8. *Flex-Bon—Johnson Paint Co.*—A two-part urethane damp-surface coating. This material may be sprayed or brushed. It cures by chemical reaction. Limited data indicate it is nonflammable and nontoxic.

9. *Gleem Vinyl Masonry Paint—Baltimore Paint & Color Works.*—A latex emulsion containing 24 pct polyvinyl acetate. It cures by water evaporation.

Permeability

The permeability coefficient of sealants was evaluated by measuring the pressure drop in a steel vessel, one side of which was enclosed by a sealant-coated wire screen. The effects of coating area and thickness, vessel volume, and type of gas were investigated. The gases used were air, carbon dioxide, Freon C-318, helium, and nitrogen.

Theoretically flow through a coating is a fuction of the viscosity rather than the molecular weight of a gas. The viscosities of the test gases and radon are nearly the same. Thus, data obtained on the test gases should apply to radon. Research is in progress to verify this supposition.

The equation derived from Darcy's formula for gas flow through porous media is as follows:

$$\ln \frac{P-P_a}{P+P_a} = \ln \frac{P_o-P_a}{P_o+P_a} - \frac{95kAP_a}{\mu eV}t, \qquad (20)$$

where

A = area of coating, in²;

k = permeability coefficient, Darcy's;

P = vessel pressure, psia;

P_i = initial vessel pressure, psia;

P_a = atmospheric pressure, psia;

t = time, sec;

u = viscosity, centipoises;

V = vessel volume, in³;

x = thickness of coating, in.

The permeability coefficient, k, is expressed in terms of unit thickness and area of the coating.

Adherence

The adherence qualities of a sealant were evaluated by measuring the force required to separate two concrete blocks joined together by the sealant. The percentage of sealant remaining on each block was noted. A plot of force per unit area against the percentage of sealant left on the two blocks provides an estimate of the sealant adherence to concrete and the sealant coherence. Five to ten tests were made with each sealant. Information on the adherence qualities of the sealants was obtained under the following four test conditions:

1. Dry—applied to dry block, 5 days air curing.
2. Dry/Wet—applied to dry block, 4 days air curing, 1 day water submersion.
3. Wet/Dry—applied to wet block, 5 days air curing.
4. Wet/Wet—applied to wet block, 5 days water submersion.

Condition 1 simulates a dry mine. Condition 2 simulates a dry mine which becomes wet after application is made. Condition 3 simulates a wet mine surface which dries after sealant is applied. Condition 4 simulates a wet mine that remains wet after application is made.

Test Results

The absolute permeability coefficient, k, and adjective rat- ings of the adherence quality of the sealants are given in table A–8. The least porous sealant has the lowest k value. The absolute values of the permeability coefficient given in table 8 are for unit thickness and unit area. When sealants are applied in mines, the coating thickness will vary. For example, Flex-Bon is essentially a paint-type product and is applied as a film 0.01 in thick; when thicker applications were attempted, the material "ran." Urethane foam expands during application and ordinarily will be 5 to 20 times thicker than the other sealants. The latex and asphalt products can be applied in any thickness desired. For this reason, data in table A–9, which considers application thickness, were prepared. The thickness of the coatings listed in table A–9, which con- siders application thickness, were prepared. The thickness of the coatings listed in table A–9, where applicable, were obtained from measurement of coatings previously applied

Table A–8.—*Permeability to gas flow and adherence ratings of sealants*

Sealant	Absolute permeability coefficient, k, darcy[1]	Adhesion rating[2]			
		Dry	Dry/Wet	Wet/Dry	Wet/Wet
Flex-Bon	$0.5 \times 10^{[illegible]}$	A	A	A	A
PL-341	$1 \times 10^{[illegible]}$	A	B	B	C
[illegible] E-771	$1.5 \times 10^{[illegible]}$	B	B	B	C
Plastic roof cement	$1.5 \times 10^{[illegible]}$	C	C	C	C
[illegible]	$1.5 \times 10^{[illegible]}$	B	B	C	C
[illegible] paint	$1.5 \times 10^{[illegible]}$	B	C	C	C
Urethane foam	$2 \times 10^{[illegible]}$	B	B	C	C
Latex AL-1000	$2.5 \times 10^{[illegible]}$	B	B	C	C
Sand-cement water, 2-2-1	$2 \times 10^{[illegible]}$	...	...	...	...
Sand-cement water, 8-4-3	$4 \times 10^{[illegible]}$	...	...	...	...

[illegible]

in the Experimental Coal Mine. If thicker, thinner or repeated applications are made for a given material, then its effectiveness as a sealant should be determined by reference to table A–8.

Table A–9.—*Relative effectiveness of sealants for restricting gas flow in practical application*

Sealant	Absolute permeability coefficient, k, darcy	Normal application thickness, inch	Relative permeability[1]
Urethane foam	2×10^{-10}	1	1
PL-241	1×10^{-10}	1/8	4
Asphalt E-771	1.5×10^{-10}	1/8	6
Plastic roof cement	1.5×10^{-10}	1/8	6
Quaker Koat	1.5×10^{-10}	1/8	6
Latex AL-1000	2.5×10^{-10}	3/32	13
Flex-Bon	$.5 \times 10^{-10}$	1/100	25
Vinyl paint	1.5×10^{-10}	1/64	48
Sand-cement-water, 2-2-1	2×10^{-6}	1/4	40,000
Sand-cement-water, 8-4-3	4×10^{-6}	1/4	80,000

[1] Relative value considering urethane foam as unity.

As normally applied in mines, the first six materials listed in table A–9 should appreciably reduce radon efflux, provided a uniform adherent coating is made. The seventh material, Flex-Bon, would be effective if the coating thickness were doubled.

The absolute permeability coefficient of the sand-cement mixtures (gunite) is about 10[illegible] darcys. Thus, the rate of gas flow through the cement mixtures is 10,000-times greater than that for the other materials. According to handbook values (*21*), the flow through the cement-sand mixtures is about the same as through the less porous sandstones and limestones. The relative high porosity of concrete to radon flow was reported previously by Russian investigators (*22*).

The coefficient, *k*, is a property of the material, independent of the gas. Of the several gases investigated, no apparent difference in flow through the sealant could be detected. The velocities varied by a factor of 1.6 and the square root of the molecular weight by 7.2. This indicates the passage of gas through the sealant due to a pressure difference in a flow rather than a diffusion process. In other experiments with various thicknesses and areas of the sealant, the data obtained were in accord with the Darcy formula.

Additional information on the practicality of four sealants —Quaker Koat, gunite, latex, and urethane foam—was obtained by tests in the Bureau's Experimental Coal Mine. These sealants were applied in 1967 in 800-ft-long sections of the entry. On dry, firm surfaces, all four sealants were in good condition 3 years later. In wet locations, the urethane foam appears to have prevented spalling better than Quaker Koat, gunite, or latex sealants. All four of these sealants adequately covered relatively smooth mine surfaces. Where prominent irregularities existed, best coverage was obtained with urethane foam.

During the present investigation, a 100-ft section of entry was sprayed with Flex-Bon. This material, applied approximately 10 mils thick, did not seal surface irregularities adequately. For effective sealing, more than a single application would be required.

Based on these observations made in the Experimental Coal Mine, the assigned letter rating A or B in table A-8 indicates satisfactory adherence. A rating of C indicates apparently unsatisfactory adherence.

Discussion

Radon gas from the strata will be entrained between the strata and the sealant. The rate this gas enters the passageway will depend on the pressure differetnial across the sealant, the thickness and permeability of the sealant, adherence, and the quality of the application. A pin hole in the sealant will negate the effetciveness of the sealant in the surrounding area. If the sealant adjacent to the pin hole does not bond properly, as much gas would flow into the passageway as if no sealant were present in this area. In many mines, where sealants are applied to the ribs and roof, it can be anticipated radon leakage will occur through the floor or at the floor-rib juncture.

Nonradioactive gases were used in the present investigation. The flow of radon gas through a sealant would differ because of its slightly higher viscosity and because of the decay of the radon gas. The longer a molecule of radon remains in the strata or sealant, the greater the probability of its decaying into particulate matter.

The permeability of five other materials was investigated. Although these sealants might not be practical for mine use, they may be effective in sealing small enclosures. These materials and their permeability coefficients are

1. Metalset A4 epoxy resin—Smooth-On Mfg. Co., Jersey City, N.J.; $k=1\times10^{-15}$ darcy.
2. Dura Weld—Penn Crete Products Co., Inc., Philadelphia, Pa.; $k=1.5\times10^{-15}$ darcy.
3. Bru-Tect II epoxy paint—Bruning Paint Co., Inc., Baltimore, Md.; $k=10^{-10}$ darcy.[6]
4. Drylok—United Gilsonite Laboratories, Scranton, Pa.; $k=10^{-6}$ darcy.[6]
5. Dura Crete—Penn Crete Products Co., Inc., Philadelphia, Pa.; $k=10^{-6}$ darcy.[6]

IDLE OR ABANDONED AREAS ADJACENT TO PRIMARY INTAKE AIRWAYS

Uranium mines should be originally designed, or eventually modified, to limit the area of exposed ore and to maintain air velocities sufficient to sweep radon and radon daughters from occupied areas as rapidly as practical. In idle, unventilated or poorly ventilated stopes and drifts, the level of radioactivity from the release and decay of radon may exceed 100,000 picocuries per liter. Such areas are major sources of mine air contamination and should be isolated from the intake air current. Isolation may be accomplished by constructing substantial stoppings coated with sealants in the access

[6] Based on limited test data.

drifts and/or in the openings to all inactive areas. This practice usually results in improved downstream air quality. Sealing abandoned or idle areas reduces intake air contamination by isolating the exposed ore surface, by preventing turbulent mixing at the entrance to access drifts, and by reducing the radon diffusion rate from the rock into the sealed area by reducing the concentration gradient between ground rock and mine opening.

The quantity of gas confined in a sealed area is related to the absolute pressure in accordance with the perfect gas law. Although mine ventilation pressure remains constant, absolute pressure varies with atmospheric changes. When the surface barometer rises, absolute pressure increases, and air flows by leakage through stoppings, ground cracks, and drillholes into the idle area. When the surface barometer falls, the flow is reversed, and highly contaminated air may enter the active areas. Sealed areas breathe continuously, consequently gob mixtures adjacent to stoppings are diluted, and in small sealed areas normal barometric movement may not be critical. However, major barometer depressions, such as those preceding a storm, can cause a severe influx of highly contaminated air from either large or small sealed regions.

In addition, major rock falls occurring within the gob may cause concussion, destroy stoppings, and inject massive contamination into the airstream.

Extensive sealed areas bordering and connected to mine airways are subject to differential ventilation pressure in addition to changes in barometric pressure. The amount of the differential is equal in magnitude to the airflow resistance of the active air courses between the first and last gob opening. If air controls such as doors or regulators are present in the airways between the first and last gob opening, the pressure differential across the gob will be equal to the sum of the water gage losses caused by both airway resistance and artificial resistance. Construction of an absolute seal is difficult. Consequently, air may leak from the mine airways through stoppings, cracks, and drillholes into the gob, pass through the sealed area, and later reenter the air stream at a point of lower pressure in a continuous low volume high contamination flow.

The problems of mass contaminant injection by gob falls and by constant flow through sealed areas can be virtually eliminated by placing the areas on reduced ventilating pressure. Reduced pressure may be induced by borehole exhaust fans or by providing bleeder connections to the primary mine return air courses. Either method creates a pressure differential from the intake to the gob and prevents contaminated air from entering the intake airways.

Figure A-29 illustrates ventilation of abandoned stopes adjacent to an intake air course and travelway. Stope ventilation is achieved by leakage through stoppings. The abandoned area was placed on reduced pressure by connecting the west side of the gob to the primary return air course through a pipe overcast and erecting stoppings in the stope access

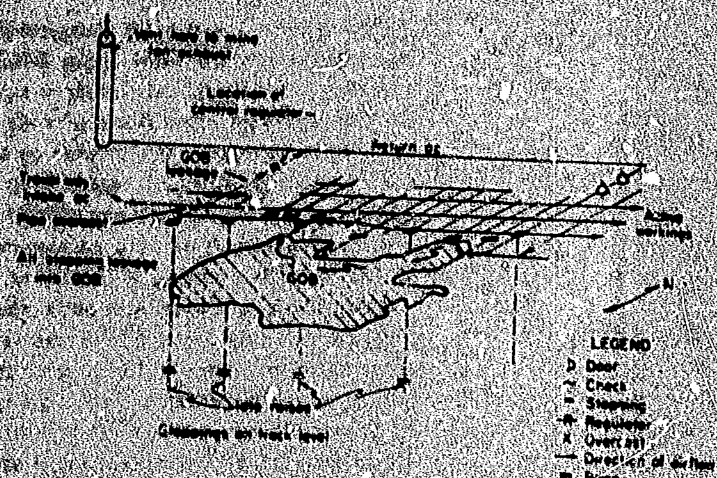

Figure A-29.—Ventilation of abandoned stopes adjacent to intake airways.

drifts. Since anticipated air volumes were low (leakage only), two 24-in-diam spiral welded pipes were adequate for overcast construction. With this system, the ventilation pressure in the gob is lower than that in the intake airways and air leakage flows from intake to return. All stoppings should be substantially constructed and sealed to limit leakage to the desired amount; however, should the pressure drop developed across the stoppings be excessive and air leakage severe, a control regulator may be installed. A pressure drop of 0.1 to 0.2 in water gage is usually adequate across gob stoppings.

The pressure differential across gob areas and the pressure gradient throughout the mine should be known by mine management and used in coursing mine air, reducing underground contamination, and planning future mine development. A complete discussion of the methods, instruments, and application of absolute pressure measurement in shallow underground mines is presented in Bureau of Mines Information Circular 7809 (*15*).

EVALUATION OF VENTILATION SYSTEM PERFORMANCE BY CONTROL SAMPLING

To maintain the efficiency of a well-designed ventilation network, to project future mine development, or to improve the performance of an unsatisfactory system, the air contaminant loading and distribution throughout the mine should be known and understood. Routine air samples taken to determine the radiation exposure of underground workmen, although related to system performance, are often affected by local conditions and may be inadequate to evaluate overall system performance. High radiation readings in working areas are frequently indicative of local malpractice rather than of a breakdown in the general ventilation system. When excessive contamination is found in a working place, the intake air quality outby the affected area should be checked to determine whether the contamination has a local source in the production area or is caused by a breakdown in the primary ventilation system. Should high radiation levels be found in

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UNITED STATES DEPARTMENT OF THE INTERIOR
Mining Enforcement and Safety Administration
Washington, D. C. 20240

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Mine Engineering and Ventilation Problems Unique to the Control of Radon Daughters

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United States Department of the Interior
mesa
Mining Enforcement and Safety Administration

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

Mining Enforcement and Safety Administration
James M. Day, Administrator

CONTENTS

ILLUSTRATIONS

MINE ENGINEERING AND VENTILATION PROBLEMS UNIQUE TO THE CONTROL OF RADON DAUGHTERS

by

R. L. Rock[1]

ABSTRACT

Quality and quantity of ventilation are the two interrelated but key factors in any radon-daughter control program. The better the intake air quality (little or no contamination from radon and its daughters), the less are the total air requirements for the ventilation of active mining areas. Engineering principles for quantity distribution of air through underground workings are straightforward and the formulae and theories governing forced ventilation are not within the scope of this paper. Rather, this paper discusses the principal methods of utilizing mine planning to facilitate radon-daughter control and also treats the more subtle features of mine ventilation which are especially critical in the ventilation of mines where radon gas constitutes an environmental contamination problem.

INTRODUCTION

Mine design and ore handling methods inevitably affect the relative difficulties encountered in controlling underground radon-daughter concentrations. The reason for this is that these two features influence both the effectiveness of mechanical ventilation and the influx of radioactive contaminants into active mine areas. The generation of radon and its short-lived daughter products cannot be prevented, but concentrations in mine atmospheres can be largely controlled through systematic arrangement of the mining sequence relative to ventilation patterns.

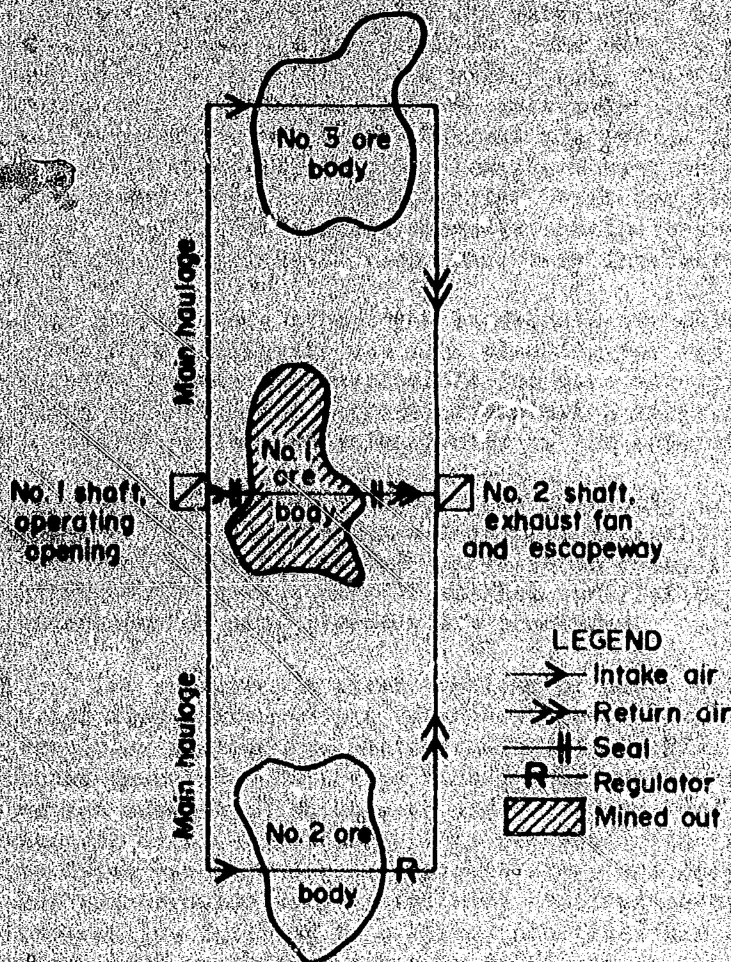
MINE PLANNING

Obviously little successful mine planning can be accomplished without reasonably accurate knowledge of both the spatial orientation and physical characteristics of the ore. Unfortunately uranium mines are notoriously difficult to delineate by drilling. Where the smaller ore deposits are involved, drilling on even 25-feet centers may sometimes yield an inaccurate picture of the orientation, continuity, quality, and quantity of ore to be mined. However, to allow maximum utilization of mine planning for radiation control purposes, ore should be delineated as thoroughly as practical by surface exploration before mining is commenced. Once the extent and configuration of

[1]Chief, Radiation Group.

the ore is known, the best mine layout for efficient ore extraction is usually quite obvious. However, mine layout to obtain maximum radon-daughter control may not be quite so apparent.

To illustrate this point, several years ago there was an exploration-development drilling program in an area in which there was no prior experience regarding ore deposition. As it turned out, the uranium values were concentrated in nearly vertical fractures occurring 5 to 10 feet apart. When drilling for developmental purposes, the drill bit repeatedly intersected one of these closely spaced fractures and, because of relative rock hardness, tended to follow the plane of the fracture. Although the intervening ground between fractures was well mineralized, it was not nearly such high grade uranium as was inferred from radiometric and chemical analyses of the drill cuttings. The mining of this particular deposit was profitable, but not to the extent that it could have been if mining and ventilation had not had to be readapted to accommodate the unanticipated mode of ore occurrence. Later development drilling in the vicinity of the first ore body was designed to transect fracture zones to reveal the true nature of the intervening rock.



Method advantages

1. Short haulageways and air courses.
2. Production and a second escapeway are achieved quickly.
3. Contamination of intake air is prevented.
4. Air can easily be shunted between No. 2 and No. 3 ore bodies.

FIGURE 1. - Plan drawing of an idealized developmental method for mining multiple uranium deposits to facilitate control over radon daughters.

Figure 1 shows a simplified and idealistic mine layout for three disconnected ore deposits alined in a somewhat linear fashion. The development openings and mining sequence depicted are designed both to enhance ore extraction efficiency and to allow radon-daughter control with a minimum amount of ventilation. Uranium mine designers must not ignore the fact that radon-daughter control is an undeniable mining cost just as are ground control, rock breakage, and ore handling.

Desirable principles of the development system shown in figure 1 are: short haulageways and air courses, the ability to achieve rapid production, and the early provision of a second exit from the mine. Contamination of intake air is precluded and the system is flexible so that available intake air can readily be shunted between ore bodies as air requirements change. Note also that all mined-out areas are kept on the return-air side of the system and that the main operating shaft and haulageway serve as intake airways. The latter feature prevents routine exposure of haulageway workers to high concentrations of radon daughters inherent in return airways.

Many factors other than inadequate ore delineation can detract from the operator's ability to use mine planning for radiation control. Financial pressures sometimes are responsible for mine managers abandoning sound mining plans for expedient methods of achieving increased production. In other instances plain short-sightedness is the apparent cause.

One problem being encountered currently is that a few relatively "low-uranium, high-vanadium" mines are being rehabilitated primarily for mining vanadium, which has become lucrative on today's market. Rehabilitation of old mines nearly always entails special ventilation problems and the potential advantages of mine planning are precluded.

The radiation control problems of newly developed mines almost always arise from mining on the advance without providing a means of diverting the resulting radioactive contaminants from working places in the ventilation currents downwind. Extensive underground exploration drifting may be practiced on the advance in which each and every ore lead is followed diligently. Because such exploration drifts are most often sinuous and explicitly designed to expose as much ore as possible, they not only create contamination problems but also provide very inefficient ventilation openings. Long-hole underground exploration drilling is a better practice than exploration drifting, but ore discovered in this way is also difficult to integrate into a systematic mining plan.

Main development openings and secondary haulageways may be driven in the ore horizon, but sublevel developmental systems are preferable for the primary intake airways and primary haulageways.

United States uranium mines developed within the last few years show evidence that considerable thought is being given to the economics of radon-daughter control. The larger the ore deposit and longer-lived the operation, the more economic advantages there are to be reaped from proper mine planning. Unlike methane, radon gas does not bleed off with time; contamination sources (mineralized rock) exposed in early mine developmental stages creates an added burden on the ventilation system throughout the life of the mine. Where a mine is operated 20 to 30 years, unnecessary contamination burdens on the ventilation system could easily add hundreds of thousands of dollars to composite ventilation costs.

Although all of the principles of mine planning which favor radon-daughter control may not be applicable in any one instance, the principles should be understood so that they can be applied effectively wherever practical.

These principles listed in order of importance are:

(1) Development openings serving as intake airways should be driven in barren ground. If ore or protore is inadvertently penetrated, it should not be mined on the advance.

(2) Mined-out areas should be maintained on the return-air side of the ventilation system insofar as practical. The advantage sought is to avoid having the contamination from nonproductive areas add to the contamination burden of active areas.

(3) Number and size of development openings connecting intake airways to active mining sections should be minimized in order to facilitate later "sealing-off" of mined-out sections.

(4) The mine should be designed so that main haulageways, hoisting stations, and other areas essential to routine production and maintenance (except for facilities which may constitute fire or explosive hazards) are in intake airways.

Mining methods, such as shrinkage stoping, which require the storage of large tonnages of broken ore underground, are not conducive to limiting the amount of radon released into the mine environment. For rock containing a given amount of Ra-266, radon is generated at a constant rate. The amount of radon emanated from the same rock into the mine atmosphere, however, is proportional to, among other things, the surface area of the rock. This explains why the practice of backfilling mined-out areas with protore or mill tailings containing Ra-266 greatly increases the potential radon contamination problem, unless, of course, such filled stopes can be positively isolated from ventilation to active mine areas.

One ore handling problem which is seldom recognized is ore spillage along intake airways. Radon contamination originating from ore spillage is much more of a problem where trackless haulage is employed. Spillage is generally related to roadway conditions, condition of haulage vehicles, travel speeds, and overloading of haulage vehicles. Over a period of time, radon contamination from accumulated ore spillage can become significant.

In one instance where an intake airway was converted from trackless haulage to track haulage, protore was used to fill low spots along the haulageway and to provide the uniform grade needed for track installation. Although the operator knew that "in-place" ore was not exposed by the haulageway, he found that the intake air (about 30,000 cfm) was contaminated to 2.0 working levels before it reached the first active mining area. The problem was very perplexing until the actual source of the contamination was discovered.

Loads of protore are often dumped into low spots along trackless haulageways to improve the drainage of ground water and such protore is capable of providing a continuous radiation contamination source.

Ground water itself carries dissolved radon but, except under unusual conditions, for example, high rates of water flow through rocks of high porosity and relatively low permeability, the added radon contribution due to the presence of ground water is usually quite low. Water under high hydrostatic pressure is capable of transporting much more radon from its point of origin within the rock to mine openings than would otherwise occur through regular diffusion processes. Ground water flowing through open drainage ditches in intake airways can release significant radon into the mine environment unless the water has been previously purged of radon when it first percolated into mine openings. In all likelihood, most dissolved radon is released immediately into the air as the water seeps into mine openings. The percentage of radon released depends on temperatures, pressures, and concentration gradients between radon in water and radon in air. In a few mines, ground water is known to be either the sole transporter or an important contributor of radon to the mine environment. Contamination control in these circumstances should be directed at isolating the flow of water from the primary intake air system.

VENTILATION

The general engineering principles for the design of a well-organized ventilation system are the same for radioactive mines as for mines which extract nonradioactive materials. The main difference is that more discipline must be applied to the more subtle aspects of good ventilating practices. Inefficiencies in ventilation are readily discernible through increased radioactivity. In fact, one investigator[a] has suggested that an improved method for evaluating the ventilation systems of nonradioactive mines might be to inject radon into the systems and use radiation measurements to determine the relative efficacy of air distribution. A more practical application for artificially induced radon might be to inject it behind mine seals to allow radiometric detection and tracing of critical leakage which may be occurring.

The added ventilating-practice disciplines required for efficient radon-daughter control are all related to the fact that the health hazard increases with elapsed time following contamination of the environment by radon because of the increase of radon-daughter concentration with time. Therefore, any factors which disrupt or retard the air-exchange process are to be avoided as much as possible.

General Ventilation Principles

The first engineering feature, which should be sought in the ventilation of radioactive mines, is the provision of adequate cross-sectional area mine

[a] Personal communication, Dr. Eugene Benton, University of San Francisco.

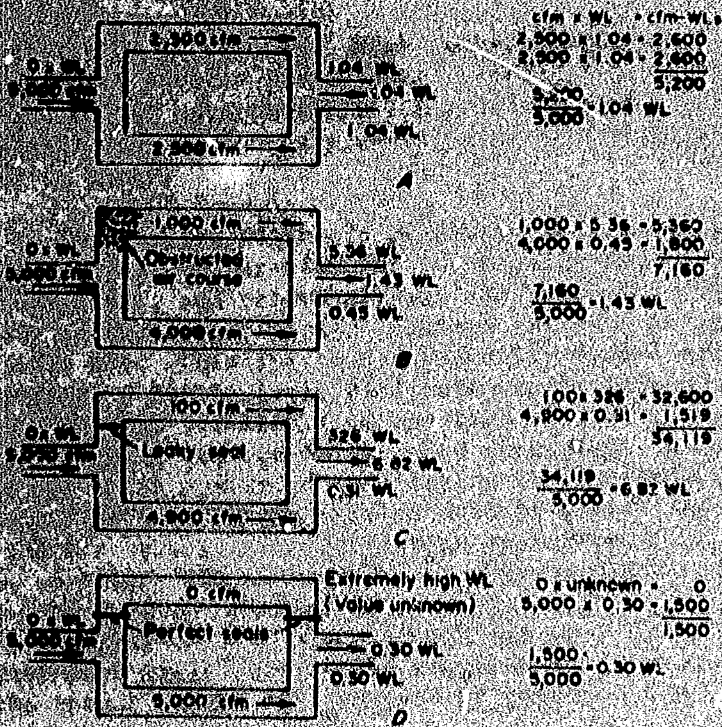
openings suitable to provide for the passage of adequate quantities of intake and return air. Size and uniformity of openings should preclude the need for excessive air velocities and air pressures. This may sound basic, but all too often this simple concept is ignored. High fan pressures require high power costs and usually result in high air velocities. High air velocities can freeze air and water lines, cause much miner discomfort, and, in some cases, increase the silica dust hazard.

Air recirculation is actually pseudoventilation which may not only be ineffectual (depending upon degree) in controlling radon daughters but also sometimes creates worse situations than would arise without mechanically induced ventilation. Air recirculation may take many forms. Probably the most common forms are recirculation within and between secondary systems. The former is usually caused by improper location of the fan inlet relative to the primary air supply. If the fan inlet is not located well upstream in the primary air supply, recirculation frequently occurs. Recirculation between secondary systems is tolerable only where the primary air quantity is great enough to dilute the contaminated air from the first system sufficiently to allow the air to be usable by the second system. Of course, the primary air supply must exceed the capacity of the auxiliary fan or fans or recirculation is inevitable.

Recirculation within the primary system is most often caused by leaky booster fan bulkheads or by leaky stoppings installed to separate intake airways from return airways. More subtle primary recirculation occurs where intake airways are, in part, large open stopes having large cross-sectional areas. In this instance, air velocities become so low, due to lack of airflow confinement, that convection currents and natural draft pressures cause a portion of the air to move aimlessly.

This same thing can happen where large active stopes are ventilated without the provision of adequate air-control corridors to distribute the air unidirectionally and uniformly through the stoping area. Sometimes, due to marked density differences, a distinct channeling of the intake air will occur through such large open stopes. When this happens, peripheral stope areas undergo a very slow air-exchange process allowing high radon-daughter concentrations to develop outside the main channel of airflow. Due to air entrainment, these high radon-daughter concentrations are gradually drawn into the main airflow causing higher overall radon-daughter concentrations to prevail than if the total airflow were more uniformly distributed throughout the entire stope.

An interesting aspect of ventilating mines for the control of radon daughters is that dead-end barren side drifts and similar openings connected to intake airways can have a decidely harmful effect on radiation control even though the side openings themselves do not emanate radon. The effect of such side openings is to provide a delay-volume which is filled with the radon-contaminated air from the connecting airway by diffusion and convection processes. The resulting radon-daughter growth time within the side opening allows the development of near equilibrium between radon and its daughters. This relatively high contamination is then gradually fed back into the main ventilating system by convection and diffusion processes. Such side openings



Figures illustrate the importance of uniform ventilation and non-leaking seals. If seals are not designed to preclude the entrance of contaminated air into intake air, they are actually detrimental to radon-daughter control. All calculations assume uniform radon emanation throughout exposed mine surface areas and are based on the equation $V_2 = V_1 (WL_1/WL_2)^{0.66}$ where V_2 = Ventilation in cubic feet per minute (cfm) after quantity changes have been made
V_1 = Initial ventilation in cfm
WL_1 = Measured WL in V_1
WL_2 = Measured WL in V_2

FIGURE 2. - Influence on radon-daughter concentrations due to proper and improper sealing.

are seldom sealed, but under some circumstances, sealing would be advisable.

Sealing of mined-out areas is a common practice to attempt to prevent radon and its daughters generated therein from contaminating active mine areas. Unfortunately most sealing projects are not very effective and some even add to the control problem. Figure 2 shows the relative effects of a perfect seal versus imperfect sealing. In reality, the radon permeability of the coating material used on seals is not nearly so important as the need to make the seal as airtight as practical. Because seals cannot be made absolutely airtight, they must be provided with a negative pressure behind them to assure that the leakage which invariably occurs is "into" and not "out from" the sealed area. Negative pressure behind seals is usually provided by high-pressure low-volume fans mounted on the surface exhausting from boreholes penetrating the sealed area.

All radioactive mines should be ventilated with a mechanical system even though, during certain periods of the year, natural draft pressures may provide more ventilation than is provided solely by the mechanical system. Both directional and quantitative control over ventilation are absolutely essential to the continuity of any radon-daughter control program. Natural ventilation cannot be relied upon for either directional or quantitative control over airflow, and does not provide an acceptable method of ventilating. Natural draft pressures can, however, sometimes be integrated advantageously into the total system.

Uranium mines and other radioactive mines having ventilation systems of any complexity should avoid discontinuing ventilation between active shifts. The growth of daughters underground over an 8- to 16-hour period without ventilation can require a considerable amount of time to be nullified after ventilation is resumed. High worker exposures can, therefore, occur over an indefinite interim period after ventilation is restored. The amount of time required for environmental control over radon daughters to be reestablished depends upon how quickly ventilation causes a complete change of underground air to occur.

Ventilation engineers presently make extensive use of boreholes for ventilation of U.S. uranium mines. Usually the main intake airway is the operating shaft, and return airways are boreholes dispersed throughout the ore body so that major mining sections are each provided with a separate split of intake air. This system has generally worked quite well. If a mining section presents a particularly difficult ventilation problem, that particular section is sometimes isolated from the rest of the ventilation system by providing the section with its own intake- and return-air boreholes. A distinct advantage of the split system of ventilating is that only that volume of air required to ventilate each mining section need be passed through it. This is in direct contrast to a series ventilation system in which the quantity of air required to ventilate the most difficult working place must be passed through the entire system. Another obvious advantage of the split system of ventilation is that radioactive contaminants are not cumulative throughout the system. Instances where ventilation requirements have become prohibitive, are usually the result of the mine operator's reliance upon extensive series ventilation.

Air Quantities Required

Air quantities required for radon-daughter control usually exceed air requirements for the control of conventional contaminants such as blasting gases, diesel exhaust gases, and dusts; but air quantity requirements need not be excessive if excessive series ventilation is not practiced. Formulas are available for calculating air quantities necessary to control specific radiation-ventilation conditions, but the data needed to make these formulas valuable are often elusive. So long as the intake air can be delivered to the mining faces relatively free of contamination, 2,000 cfm of air will ventilate adequately a 10- x 10-foot face of high-grade ore. As the intake air becomes contaminated above 0.1 working level, however, air quantities required for control increase rapidly. Figure 3 shows the factors by which air quantities needed for control increase as the intake air becomes contaminated.

Maintenance

Maintenance of ventilation systems plays an important part in determining the radiation exposures that underground workers ultimately experience. No matter how well planned and installed the ventilation system is initially, the system must be maintained or efficiency rapidly deteriorates. Maintenance is often badly neglected, unless a ventilation engineer or some other knowledgeable person familiar with the radiation hazard is assigned direct responsibility for maintaining adequate ventilation. Persons assigned this responsibility must be willing to apply themselves fully to the problem and must have authority to make the corrections or repairs to the ventilation system necessary to maintain healthful conditions.

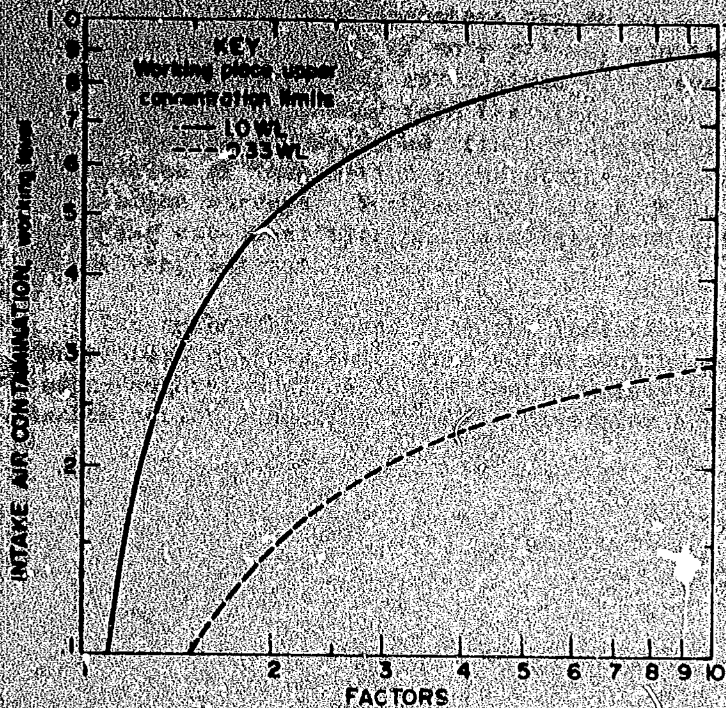


FIGURE 3. - Factors by which air volume must be increased when contaminated air is used for ventilation.

CONCLUSION

Control of radon daughters in radioactive mines is sometimes considered to be basically a ventilation problem. The problem is, however, of such a nature that control over the amount of contamination released into the mine environment plus control over the manner in which that contamination is removed from the mine environment relative to occupied mine areas are of major importance in determining the difficulty of ventilation.

In many respects, radon-daughter control involves different considerations than are involved in more conventional mine contaminants. One reason this is true is because of the rapid growth of the hazard (radon daughters) following contamination of the air with the parent radon. Another reason is that so few atoms of radon emanating from so many different sources can be involved in total mine contamination difficulties.

Having worked on ventilation problems involving dust, blasting gases, diesel exhaust gases, and methane, the author can state that solutions to high radon-daughter concentrations often require more finesse than the aforementioned problems.

The best method for providing practical solutions to radon-daughter control difficulties is to first make a detailed assessment of contamination sources relative to existing air distribution. Detection of subtle contamination causes may require highly trained personnel using specialized equipment. Usually the mine must be considered in its entirety during the contamination assessment program. Answers sought are:

(1) Where and why major contamination problems are occurring.

(2) How beneficial changes may be affected without causing harmful effects in other active mine areas.

(3) What major changes, such as increased primary airflow, are necessary to assure long-range environmental control over radon-daughter concentrations.

Far too many mine operators try to solve their radiation problems by indiscriminate addition of more primary ventilation. Increased air quantity is often necessary, but, for maximum effectiveness, additional air must be integrated appropriately into the ventilation system. The only way this integration can be accomplished with any degree of certainty of success is through utilization of information gathered in preliminary detailed radiation-ventilation surveys. Such surveys are time-consuming in that they require measuring air quantities and associated radiation in all the separate branches of the ventilation system.

The author has found from the radiation-ventilation surveys conducted by the radiation group that, in a surprising number of instances, satisfactory radon-daughter control is attainable merely by containment and/or diversion of contamination emanating from inactive mine areas.

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