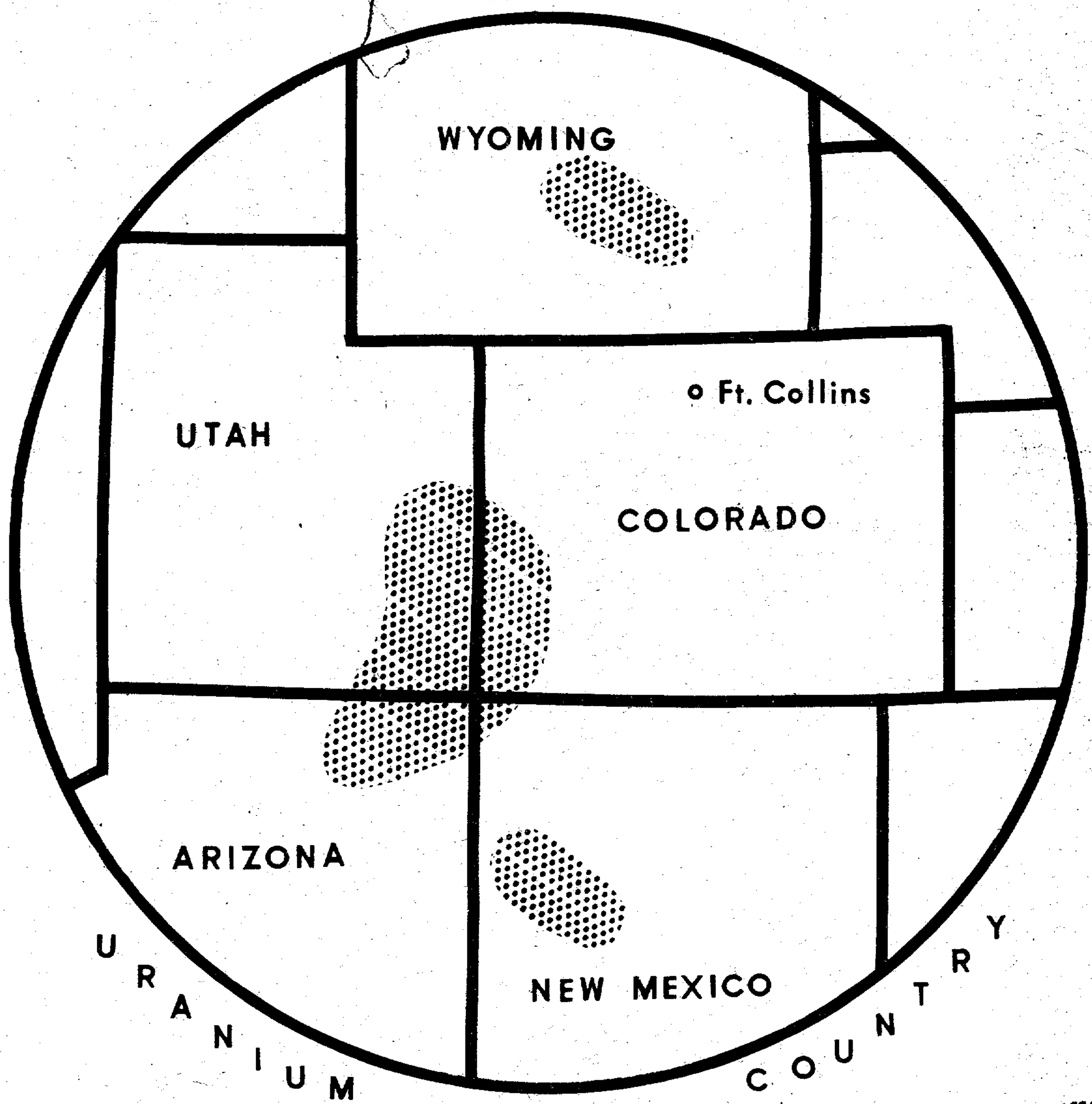
COO 1500-15

RADON PROGENY INHALATION STUDY

AS APPLICABLE TO URANIUM MINING



FOURTH ANNUAL PROGRESS REPORT on
U.S. Atomic Energy Commission Contract No.
AT (11-1)-1500
For Calendar Year 1968

COLORADO STATE UNIVERSITY - FT. COLLINS, COLO.

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COO-1500-15

Fourth Annual Progress Report on U. S. Atomic Energy Commission Contract No. AT(11-1)-1500

for research entitled

RADON PROGENY INHALATION STUDY

As Applicable to Uranium Mining Operations

covering the period
Calendar Year 1968

By Co-principal Investigators

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Submitted February 28, 1969

ACKNOWLEDGEMENTS

The work described in this progress report was conducted within the Department of Radiology and Radiation Biology of Colorado State University under Contract AT(11-1)-1500 with the U. S. Atomic Energy Commission. Additional studies closely related to those performed under the USAEC contract were supported by a contract with the U. S. Public Health Service. Since a large portion of the work performed under the two contracts is interdependent, the support received from both agencies is gratefully acknowledged.

During the year many measurements were made of atmospheric radon progeny concentrations in working uranium mines. The cooperation and consideration extended to us by the mining companies and their employees were major factors in the successful completion of the work performed during the year. In particular we would like to express our thanks to the companies and individuals listed below:

Cotter Corporation (Schwartzwalder Mine):
Ed Rice, Clyde True and Bert Jones.

Kerr-McGee Corporation:
Jack L. Robison, Billy Stevens, Jim Cleveland, Rod Tregembo, Al Alkhafi, Bruce Lilly, Leon Maynard, Maurice Korbe and Ray Nanco.

United Nuclear - Homestake Partners:
L. W. Swent, Milt Ward, Jack Hawn and Ed Kanizar.

A Special Workshop on Uranium Mining Health Physics was held in Denver, Colorado on June 21 and 22, 1968. The workshop proved to be a valuable forum for the exchange of ideas on both practical and theoretical aspects of radiation control in uranium mines. We sincerely appreciate the many ideas and suggestions contributed by many of the 175 participants in the workshop. The Health Physics Society and its Central Rocky Mountain Chapter co-sponsored the workshop and for that we extend our appreciation to the officers and directors of those organizations.

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I. INTRODUCTION

Review of the Problem

A very thorough review of the problem of radiation exposures to uranium miners was produced during the hearings held by the Joint Committee on Atomic Energy, U. S. Congress, during the summer of 1967 (1). Part 2 of the record of the hearings contains reprints of the relevant information available on the subject. Readers of this report who are interested in a complete review of the problem are referred to those documents.

Research Objectives

The research work conducted under this contract was designed to meet the following three broad objectives:

1) To investigate the physical characteristics of the radioactive aerosols found in uranium mine atmospheres and to correlate these characteristics with patterns of deposition and clearance of the aerosols in the human respiratory tract.

2) To investigate and develop practical field methods for measuring and evaluating inhalation exposures received by individual uranium miners.

3) To investigate and evaluate methods for controlling exposures of uranium miners to airborne radioactive materials.

Report Format

During 1968 three graduate students working on this project completed the requirements for the Doctor of Philosophy degree. Since their research was supported by and directly a part of this project, their dissertations were published as special project reports. Each of these special reports represents the completion of one sub-project or a major phase of a sub-project.

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(1) Radiation Exposure of Uranium Miners, hearings held May-August, 1967, before the Joint Committee on Atomic Energy, 90th Congress, 1st Session, Parts 1 and 2, U. S. Govt. Print. Office, Washington, D. C., 1967.

Five papers covering various aspects of the work performed as part of this research were presented at the special workshop in Denver during June 1968. These five papers and one additional paper not presented at the workshop have been submitted to the Health Physics Journal for publication. Since these papers will soon appear in print, only the abstracts are included in this report, merely to indicate the subject matter of each paper.

A fourth special report on the subject of thermoluminescent dosimetry for uranium miners (also a Ph.D. Dissertation) will be completed and published by May 1969.

Nearly all of the research data obtained through 1968 have been included in one or more of the reports or papers mentioned above. Consequently, this annual progress report will differ significantly from those submitted in the past. Each sub-project will be described very briefly with an emphasis on current status and major accomplishments in 1968. The publications containing the technical data will be indicated.

List of Publications

Published prior to current contract year:

COO-1500-1 Dahl, A. H., K. J. Schiager, R. J. Reece and P. W. Jacoe, Radon decay products inhalation study, 1st annual progress report, Feb. 28, 1966.

COO-1500-2 Schiager, K. J., Inhalation hazards of radon decay products in uranium mines, Nuclear News, 9(No. 6): 21-23, June, 1966.

COO-1500-3 Dahl, A. H., K. J. Schiager, R. J. Reece and P. W. Jacoe, Radon progeny inhalation study, 2nd annual progress report, Feb. 28, 1967.

COO-1500-4 Schiager, K. J., Statement in Radiation Exposure of Uranium Miners, hearings held May-August, 1967, before the Joint Committee on Atomic Energy, 90th Congress, 1st Session, Part 1, pp. 381-388, U. S. Govt. Print. Office, Washington, D. C., 1967.

COO-1500-5 Schiager, K. J., A. H. Dahl, R. J. Reece and P. W. Jacoe, Radon progeny inhalation study, 3rd annual progress report, Feb. 29, 1968.

COO-1500-6 Schiager, K. J. and A. H. Dahl, Radon progeny inhalation study, 3rd year summary report, Feb. 29, 1968.

Papers presented at the Special Workshop on Uranium Mining Health Physics*, June 21-22, 1968 and subsequently submitted for publication in Health Physics (abstracts included in this progress report):

COO-1500-7 Martz, D. E., D. F. Holleman, D. E. McCurdy and K. J. Schiager, Analysis of atmospheric concentrations of RaA, RaB and RaC by alpha spectroscopy.

COO-1500-8 Martz, D. E. and K. J. Schiager, Protection against radon progeny inhalation using filter type respirators.

COO-1500-11 Holleman, D. F., D. E. Martz and K. J. Schiager, Total respiratory deposition of radon daughters from inhalation of uranium mine atmospheres.

COO-1500-13 Gotchy, R. L. and K. J. Schiager, Bioassay methods for estimating current exposures to the short-lived radon progeny.

COO-1500-14 McCurdy, D. E., K. J. Schiager and E. D. Flack, Thermoluminescent dosimetry for personal monitoring of uranium miners.

Special project reports published since June, 1968 (abstracts included in this progress report):

COO-1500-9 Martz, D. E., Respiratory protection for uranium miners (Ph.D. Dissertation), June, 1968.

COO-1500-10 Gotchy, R. L., A survey of bioassays for uranium miners (Ph.D. Dissertation), June, 1968.

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* The publication date is expected to be sometime during the spring of 1969.

COO-1500-12 Holleman, D. F., Radiation dosimetry for the respiratory tract of uranium miners (Ph.D. Dissertation), December, 1968.

Related Activities

The following oral presentations were made during this contract period, but have not been published:

Martz, D. E. and K. J. Schiager, Respiratory protection against radon progeny: an evaluation of devices by in vivo gamma-ray counting, presented at the American Industrial Hygiene Conference, St. Louis, Mo., May 15, 1968.

McCurdy, D. E. and K. J. Schiager, Aerosol characterization of radon progeny in mine atmospheres, presented at the American Industrial Hygiene Conference, St. Louis, Mo., May 16, 1968.

Schiager, K. J., Comments on Radiation Standards for Uranium Mining, 41 CFR 50-204.321, presented before the Hearing Examiner, Bureau of Labor Standards, U. S. Dept. of Labor, Washington, D. C., November 21, 1968 (appended to this progress report).

Two exhibits were displayed at the annual meeting of the Health Physics Society held in Denver, June 16-20, 1968. Exhibit spaces were provided by the Society for educational and scientific exhibits at no charge to the exhibitor. This provided an excellent opportunity to familiarize other health physicists with the health physics problems in uranium mining, and with this research project in particular. The titles and descriptions of the two exhibits were as follows:

Mobile In Vivo Analyzer

A shadow-shield in-vivo gamma-ray analyzer was constructed specifically for determining deposition of radon progeny in the lungs of uranium miners. In order to transport the counter to uranium mine locations, a trailer was designed and constructed to be towed by a pickup truck over rough, mountain roads.

Uranium Mining Health Physics

Thermoluminescent dosimetry applied to personal monitoring of airborne radon progeny exposures to uranium miners. General information pertaining to the Radiation Health Specialists Training Program at Colorado State University will also be displayed.

II. AEROSOL CHARACTERISTICS AND DEPOSITION

Alpha-Energy Spectroscopy

The analytical techniques for quantitatively determining the atmospheric concentrations of the individual short-lived radon progeny by alpha spectroscopy were perfected. The method (described in COO-1500-7) was designed for research applications for which accuracy is important, rather than for routine field use. The method has proved to be invaluable for studying particle size distributions and relative concentrations of the short-lived daughters under extreme conditions of non-equilibrium.

Analysis of Atmospheric Concentrations
of RaA, RaB and RaC by Alpha Spectroscopy

(COO-1500-7)

Dowell E. Martz, Dan F. Holleman
David E. McCurdy and Keith J. Schiager

Abstract

A new method is presented for determining the airborne concentrations of RaA, RaB and RaC in atmospheres contaminated with Radon-222. The method employs alpha spectroscopy to measure the count rates of RaA and RaC' present on a membrane filter sample at two post-sampling times. The individual air concentrations and the statistical variances associated with each then may be calculated from the equations given. Theoretical and experimental comparisons are presented which indicate the improved accuracy of the spectroscopic method over methods previously available.

Respiratory Deposition Studies

Measurements of total and differential deposition of the short-lived radon progeny in the respiratory tract were completed and estimates were made of dose to the respiratory epithelium per Working Level Month exposure. Most of these measurements were made with actual mine atmospheres as the sources of exposure and, therefore, represent exposure conditions as they currently exist in uranium mines. However, the techniques developed during this study are uniquely applicable to a more generalized study of characteristics and respiratory tract deposition of many sub-micron size aerosols. Continuing studies are planned to exploit the methods and equipment now available.

Total Respiratory Deposition of Radon Daughters from Inhalation of Uranium Mine Atmospheres

(COO-1500-11)

Dan F. Holleman, Dowell E. Martz
and Keith J. Schiager

Abstract

Total deposition in the human respiratory tract of the short-lived radon progeny present in a "typical" uranium mine atmosphere was determined in thirty separate experiments. Effective diffusion coefficients for the total radon progeny activity were determined by diffusion tube sampling of the exposure atmosphere, and concentrations of RaA, RaB and RaC were measured in both the inspired and exhaled air. Respiration rates and tidal volumes were also measured for each experiment.

Total percent Working Level depositions, defined by the relationship:

$$100 \left[1 - \frac{\text{WL in exhaled air}}{\text{WL in inspired air}} \right]$$, were in the range of 30 to 65%. Percent depositions for individual radon daughters were also measured, with mean values of 50.4%, 44.7% and 40.6% determined for RaA, RaB, and RaC, respectively, for an average respiration rate of 18 min.$^{-1}$ and an average tidal volume of 1.2 liters.

The experimentally determined relationships between total deposition and respiratory rate and tidal volume are presented.

Radiation Dosimetry for the Respiratory Tract of Uranium Miners

(COO-1500-12)

Dan F. Holleman

Abstract

Factors affecting the radiation dose to the respiratory tract of uranium miners were investigated. These included atmospheric constitution, deposition of radioactivity in the respiratory tract and physiological translocation. Several aspects of the uranium mine atmosphere were considered, such as radon and radon daughter activity concentrations, physical form and activity-size distribution of the radon daughters, relative humidity and air temperature. Activity concentrations were found to be extremely variable, however, the remaining atmospheric factors were reasonably stable. Less than ten percent of the radon daughters were unattached. The attached fraction could apparently be represented by a mean diffusion coefficient of 1.3×10^{-5} cm^2/sec or an aerodynamic size of 0.067 microns. This diffusion coefficient was not significantly affected by the presence of atmospheric particles produced during normal mining operations.

Total and regional deposition percentages were determined experimentally as well as theoretically. Percent total deposition values for individual radon daughters were 50, 45 and 41 for radium-A, radium-B and radium-C, respectively, for an average respiration rate of 18 min^{-1} and an average tidal volume of 1.2 liters. The influence of respiration rate and tidal volume upon total deposition was examined. Regional deposition fractions for the nasal cavity, tracheobronchial and pulmonary regions were 22, 15 and 63 percent of the total deposited activity, respectively, for nose-breathing.

Physiological translocation of respiratory deposited activity was investigated for various regions of the respiratory system. Results indicated that ciliary translocation was of negligible importance in the dosimetry of inhaled radon daughters.

Radiation dose rates to the respiratory epithelium of uranium miners were evaluated by in-vivo gamma-ray counting techniques. The calculated dose per working level month exposure was 0.8 rads/WLM to the basal cells of the tertiary bronchioles (36 micron mucus-tissue depth). The radioactivity was assumed to be uniformly distributed on the epithelial surface lining. The calculated average organ lung dose rate was 0.1 rads/WLM. The calculated dose from radon and radon daughters absorbed in tissue contributed negligibly to the total dose. The measured external gamma-ray dose rates were 4.0 rem/yr and less than 1 rem/yr for selected areas in the Schwartzwalder and New Mexico Mines, respectively.

Laboratory Aerosol Chamber

A chamber was constructed for use in conducting controlled atmosphere inhalation studies. The chamber was constructed of galvanized sheet metal, with dimensions of 4.3 m long by 1.4 m wide x 2.0 m high, and a contained volume of approximately 12,000 liters. Human exposure subjects enter and leave the chamber through a double door airlock to minimize the exchange of chamber air with laboratory room air. A large window permits viewing the experimental subject from outside the chamber.

The chamber was designed so that uranium mine atmospheres could be simulated in the laboratory. A non-exchanging refrigeration unit provides for temperature regulation from ambient room temperature down to approximately 55^{o}F. Electric space heaters can be used to produce temperatures above ambient room temperature. Relative humidity in the chamber can be adjusted by circulating the chamber atmosphere through water bubblers or desiccators, as necessary. Aerosols can be removed by circulating the chamber atmosphere through high efficiency filters; they can be added by injecting natural or artificially produced particles into the chamber.

Two radon isotopes (^{220}Rn and ^{222}Rn) have been used as sources of radio-aerosols in studies conducted during the past year. The second decay product in the ^{220}Rn series is ^{212}Pb with a 10.64 hour half-life. The ^{212}Pb permits a better evaluation of the in vivo activity distribution than do the short-lived progeny of ^{222}Rn, owing to its longer half-life. It also has the advantage that it can be treated as a single nuclide, rather than a series of short-lived isotopes, for counting purposes. The physical and chemical characteristics of the ^{212}Pb aerosol are expected to be essentially identical to those of the ^{218}Po - ^{214}Pb - ^{214}Bi - ^{214}Po chain arising from ^{222}Rn. These properties make the ^{212}Pb aerosol a particularly valuable material for studying respiratory deposition and translocation of uranium mine aerosols.

Behavior of Sub-micron-sized Aerosols

The study of uranium mine atmospheres has resulted in the development of techniques for investigating the physical properties and physiological behavior of extremely small aerosols (in the range of 0.001 to 0.1 micron). Although the methods were developed specifically for studying the short-lived progeny of ^{222}Rn, they are easily adaptable to general studies of small particle inhalation exposures.

Aerosols in the 0.001 to 0.1 micron size range can be produced quite easily by the decay of either ^{220}Rn or ^{222}Rn in controlled atmospheres. Concentrations of these aerosols in air are readily determined by alpha- and gamma-energy spectrometry. Deposition and translocation in the respiratory tract can be investigated by in vivo gamma-ray counting. One of the major limitations at the present time, however, is the method of determining aerodynamic particle sizes in the sub-micron region. Diffusion tube analyses are limited in size-discrimination sensitivity. Other methods are being developed and adapted to overcome these limitations. Among the methods being considered are inertial separation of particle sizes with a conifuge, and size-selective thermal precipitation.

III. EXPOSURE EVALUATION METHODS

Exposure Monitoring with Thermoluminescent Dosimeters

The initial development of a personal monitoring system for uranium miners, utilizing thermoluminescent dosimetry (TLD), was completed early in this contract period. A field evaluation study was begun in four mines in the Ambrosia Lake, New Mexico area under a contract with the U. S. Public Health Service. In addition to the field evaluation, further studies were made of the luminescent response characteristics of CaF_2:Dy, which appears to be the best thermoluminescent material presently available for this application.

Although the current field work is being performed under contract with the USPHS and is not yet completed, a few observations are appropriate at this time:

1. The filter media (0.65 micron membrane filters) and the filter holders (0.5 inch diameter "Swinney" type with Luer-Lok fittings) have proven satisfactory. It was found to be necessary, however, to seal the filter holders with a silicone rubber compound after loading to prevent air leakage through the threaded body and to prevent accidental opening.

2. Although many filters returned from the mines exhibit heavy loading with diesel smoke, air flow rate calibrations before and after use indicate essentially no change in flow rate as a result of dust or smoke loading.

3. The personal air sampler pumps are the weak link in the entire system. The Casella pump was selected for use with the system because it appeared to have the most desirable features, and seemed to be the most rugged of five or six brands tested. However, almost every conceivable type of malfunction has been experienced during the few months the pumps have been in use. Some of the inherent flaws have been corrected by modifying and sealing the pump cases. It is hoped that through an intensive preventive maintenance program it will be possible to obtain one year of field use

from the pumps. It is obvious, however, that improvements of the pumps are essential to the routine application of this monitoring system in uranium mines.

The following abstract is for a paper presented at the special workshop in Denver, and subsequently submitted to Health Physics for publication:

Thermoluminescent Dosimetry for Personal Monitoring of Uranium Miners

(COO-1500-14)

David E. McCurdy, Keith J. Schiager and Edwin D. Flack

Abstract

An accurate dosimetry system using thermoluminescent detectors has been developed for monitoring radiation exposures to individual uranium miners. The system permits the evaluation of cumulative exposures to airborne radon progeny, expressed in units of Working Level Months, as well as the external gamma-ray exposure originating from the ore bodies. Thermoluminescent materials such as LiF, CaF_2:Dy and $CaSO_4$:Mn have been evaluated as possible alpha-sensitive detectors of radon progeny collected on a filter paper. The most promising TLD utilizes CaF_2:Dy, and is sufficiently sensitive to detect the accumulation of 10^5 MeV of latent alpha energy collected on a filter paper. Proper annealing of the CaF_2:Dy crystal provides two response peaks, at 185°C and 265°C, for which fading is negligible for any proposed monitoring period.

Bioassay Monitoring Developments

The first phase of the bioassay program was completed early in this contract period. This phase demonstrated the positive correlation between the concentrations of long-lived radon progeny in biological media and occupational exposures to airborne short-lived radon progeny. The preliminary investigations, however, were not comprehensive enough to determine whether or not short-term, low-level inhalation exposures could be adequately documented by bioassay monitoring methods.

A larger scale field evaluation of bioassay monitoring has been initiated in conjunction with the TLD personal monitoring program under the contract with the U. S. Public Health Service. Forty miners, working in four mines in the Ambrosia Lake (Grants), New Mexico area, are contributing daily whisker samples; about twenty-five of these miners are also contributing blood samples monthly. In addition, ten long-term local residents who have never worked in uranium mines or mills are contributing whiskers daily and blood samples monthly. From these control subjects it is hoped that the non-occupational contributions to the ^{210}Pb and ^{210}Po in blood and whiskers can be established. Data from these studies are not yet available.

The following abstracts are for: (1) a paper presented at the special workshop in Denver and accepted for publication in Health Physics, and (2) a Ph.D. dissertation covering the same material and submitted earlier as a special report:

Bioassay Methods for Estimating
Current Exposures to the Short-Lived
Radon Progeny

(COO-1500-13)

R. L. Gotchy and K. J. Schiager

Abstract

Concentrations of ^{210}Pb (RaD) and ^{210}Po (RaF) were measured in the urine, feces, blood, hair and whiskers from 25 people associated with the operation of a uranium mine near Golden, Colorado. The concentrations of ^{210}Pb and ^{210}Po in blood, hair and whiskers were found to be correlated with occupational exposure by power function relationships. Blood levels of ^{210}Pb and ^{210}Po provide reasonable estimates of mean exposure levels in the range of 1 to 5 working levels ($\pm$ 50% or better) for samples pooled for one or more calendar quarters. ^{210}Pb or ^{210}Po activity in either hair or whiskers

can be used to estimate mean exposure levels in the range of 0.4 to 7 working levels (± 50% or better) when samples are pooled for one or more calendar quarters.

A decreasing exponential relationship was found between ^{210}Pb to ^{210}Po activity ratios in the blood of working uranium miners and years of underground experience. Possible applications of these relationships to exposure monitoring and some of the inherent problems associated with bioassays for uranium miners are discussed.

A Survey of Bioassays
for Uranium Miners

(COO-1500-10)

Reginald L. Gotchy

Abstract

Concentrations of RaD (^{210}Pb) and RaF (^{210}Po) were measured in the urine, feces, blood, hair and whiskers of approximately two dozen people associated with the operation of the Schwartzwalder uranium mine near Golden, Colorado. The results of the study supported the hypothesis that analyses of RaD and RaF in biological samples can be used to evaluate and regulate occupational exposures of uranium miners to the short-lived progeny of radon-222.

Although RaD and RaF concentrations in the urine and feces of uranium miners were much higher than those in non-exposed humans, there was no evidence of a correlation between bioassay data and mean occupational exposure.

Blood concentrations of RaD and RaF showed a correlation with mean exposures of uranium miners. Power functions relating mean working levels ($\overline{WL}$) of exposure with RaD and RaF levels in blood were; $\overline{WL} = 0.244$ (pCi RaD/ $)^{0.605}$ and $\overline{WL} = 0.421$ (pCi RaF/ $)^{0.386}$, respectively. The corresponding correlation coefficients were 0.74 and 0.77. An inverse exponential relationship was observed between the RaF to RaD activity ratio in blood and years of work underground. The relationship was; $(RaF:RaD) = 4.84\, e^{-0.0842t}$, where t was years underground.

The correlation coefficient was 0.85. All correlations were significant at the one percent level. Good correlations were found between estimated $\overline{WL}$ and RaD and RaF activities in hair and whisker samples. The power functions relating $\overline{WL}$ with RaD and RaF in hair were: $\overline{WL} = 0.478\ (\text{pCi RaD/g})^{0.700}$ and $\overline{WL} = 0.238\ (\text{pCi RaF/g})^{0.741}$, respectively. The corresponding correlation coefficients were 0.86 and 0.89. The power functions relating $\overline{WL}$ and RaD and RaF in whiskers were: $\overline{WL} = 0.443\ (\text{pCi RaD/g})^{0.713}$ and $\overline{WL} = 0.246\ (\text{pCi RaF/g})^{0.691}$, respectively. The corresponding correlation coefficients were 0.88 and 0.92. All correlations were significant at the one percent level.

The bioassay data indicated that the contribution of RaD and RaF from natural sources in Colorado may result in significant errors when attempting to estimate low level occupational exposures from the observed RaD and RaF levels in bioassay samples. Regression analyses performed on RaF data for hair and whiskers that were "corrected" for the estimated background levels showed an improved fit. The "corrected" regression lines for RaF in hair and whiskers were: $\overline{WL} = 0.290\ (\text{pCi/g hair})^{0.685}$ and $\overline{WL} = 0.311\ (\text{pCi/g whiskers})^{0.633}$, respectively. The corresponding correlation coefficients were 0.91 and 0.92. All correlations were significant at the one percent level.

Problems involved in the determination of background levels of RaD and RaF for uranium miners, and a possible solution were discussed.

IV. EXPOSURE CONTROL METHODS

Respiratory Protection

An investigation of the protection efficiencies afforded by commercially available filter-type respirators against inhalation of radon progeny was completed early during this contract year. These evaluations were unique in that they accurately determined the total efficiency of the respirator while in actual use, rather than relying on measurements of filter cartridge efficiencies alone.

A suitable filter media, combining relatively high efficiency with low breathing resistance, was identified. This material, a resin-impregnated wool fiber pad, was initially available only from a British supplier. However, as a result of its identification as an appropriate respirator filter medium for use by uranium miners, several U. S. manufacturers have proceeded with its development and supply in this country.

Respirator evaluations under this contract were discontinued in the summer of 1968. One paper on respiratory protection was presented at the special workshop in Denver and subsequently accepted for publication in Health Physics. A Ph.D. dissertation also resulted from the respirator evaluation program and was submitted as a special report in June, 1968. The abstracts of these papers follow:

Protection Against Radon Progeny
Inhalation using Filter Type Respirators

(COO-1500-8)

Dowell E. Martz and Keith J. Schiager

Abstract

The efficiencies of several respiratory protective devices in removing the airborne radon daughter activity found in underground uranium mines were determined under standardized test conditions. The protection afforded to working uranium miners by simple filter respirators was estimated

by comparison in vivo counting of the internally deposited RaC activity present in the respiratory systems of miners at the end of the working shift. The mean protection efficiency obtained was 85.2 ± 13.8%, based on in vivo counts of 21 miners. The problem of providing adequate respiratory protection for underground uranium miners is discussed and a suggested list of criteria for respirator design is given.

Respiratory Protection for Uranium Miners

(COO-1500-9)

Dowell E. Martz

Abstract

A method of analyzing filter samples by alpha spectroscopy was developed for accurately determining the airborne concentrations of RaA, RaB, and RaC in atmospheres contaminated with radon. The method was used to determine the concentration of radon daughter products in a uranium mine atmosphere and to evaluate respiratory protective devices worn by miners.

Measurements of the radon daughter activity deposited in the respiratory tract of person exposed to a representative mine atmosphere indicated average percent depositions of 50.7%, 43.9% and 41.4% for the RaA, RaB and RaC components. The fraction of the activity deposited depended on the properties of the aerosol inhaled and on the breathing pattern of the subject. Increased deposition was observed for large tidal volumes and low breathing rates.

Several commercial and experimental respirator filters were tested for their ability to remove the radon daughter activity encountered in a mine atmosphere. High removal efficiencies were exhibited by densely packed fiber filters and by resin-impregnated wool filters.

An in vivo counting system capable of detecting the RaC activity present in the respiratory tract of working miners was used to estimate the protection afforded by respirators under mining conditions. Protection factors of 5 to 10 were achieved by several commercial respirators.

V. SUMMARY

The Radon Progeny Inhalation Study has been undergoing a period of transition during 1968. The emphasis of the project has changed somewhat as the result of the completion of three sub-projects and the initiation of other sub-projects. These transitions have been accompanied by an almost complete turnover of graduate student research assistants working on the project.

Three students who have been supported at least partially by this contract completed the requirements for the Ph.D. degree during 1968. A fourth student will complete the Ph.D. requirements before the end of this contract period (May 31, 1969). Another student supported by this contract completed the requirements for the M.S. degree during the year. Each of these students made significant contributions to this research project. As of Spring 1969 three new graduate research assistants are being supported under this contract to replace those who have left.

A large amount of the work performed under this contract during the first three and a half years involved developmental investigations and qualitative measurements. Many of the experiments were conducted under pressure to obtain immediate answers to be utilized by regulatory agencies. The pressure to produce immediate answers now seems to be somewhat relaxed and the nature of the investigations is now becoming more sophiscated and quantitative.

The initial measurements of mine aerosols have shown that a majority of the particles are less than 0.07 microns in diameter. These data were obtained by diffusion tube sampling; however, other methods must be used to obtain more precise data on particle size distributions in the 0.001 to 0.1 micron range. The effects of ventilation control on radon progeny aerosols in uranium mines should be determined more precisely in order to provide guidance to the uranium mining industry on appropriate ventilation control methods. Techniques for determining particle size distributions of the radon progeny aerosols are being investigated and developed.

Measurements were made of both total and differential deposition of radon progeny aerosols in the respiratory tract of uranium miners. Theoretical lung models were applied to the experimental data to obtain improved estimates of the radiation dose to the respiratory epithelium as a function of Working Level Months exposure. The calculated value obtained from these measurements was 0.8 rads/WLM.

As soon as a good method is developed for determining sub-micron particle size distributions additional measurements will be made to relate respiratory tract deposition with particle size. The radon progeny aerosols provide a unique tool for studying deposition of sub-micron sized aerosols, although the information would have much wider applications.

The initial phase of the bioassay studies proved conclusively that a correlation exits between the concentrations of long-lived radon progeny in biological samples and occupational exposures to airborne short-lived radon progeny. These studies also indicated that blood and whiskers were the most promising bioassay media. The studies now in progress (under USPHS sponsorship) are designed to determine whether or not bioassay methods can be used to document accurately a miners current occupational exposure to the short-lived radon progeny.

The study of protection against radon progeny inhalation afforded by commercially available filter-type respirators was completed during the year. Deep pads of resin impregnated wool fibers were found to be the most satisfactory filter material. Respirator canisters containing this material are now being developed and marketed by U. S. manufacturers.

A laboratory aerosol inhalation chamber was constructed for use in aerosol behavior studies and respiratory deposition measurements with controlled atmospheres. Two isotopes of radon (^{220}Rn and ^{222}Rn) have been used as precursors of radioaerosols. Estimates of aerosol size distributions were made by diffusion tube analyses, but methods that should give greater precision are being investigated and developed.

The TLD-air sampler system for monitoring exposures to individual miners has been undergoing continual study and improvement during the year. A field evaluation involving forty miners is in progress; present prognosis is that the system will accurately measure the radon progeny concentrations to which the miner is exposed, provided that the air pump mechanism is improved to withstand the severe conditions of use.

This research project has been brought to the attention of the uranium mining industry as well as to the health physics profession. Much progress has been made toward solving the problems of radiation exposure to uranium miners; however, much work still needs to be done before the radiation protection of uranium miners will be as complete and reliable as that afforded to radiation workers in other industries.

APPENDIX A

Comments on

Radiation Standards for Uranium Mining

41 CFR 50-204.321

prepared for hearings to be held

November 20- , 1968
by the
Bureau of Labor Standards
Wage and Labor Standards Administration
U.S. Department of Labor

by
Keith J. Schiager, Ph.D.
Associate Professor of Radiation Biology
Colorado State University
Fort Collins, Colorado

Comments on "Radiation Standards for Uranium Mining"
41 CFR 50-204.321
RADON PROGENY CONCENTRATION UNITS

The Working Level Unit

The "Working Level" (WL) is a concentration unit for radon progeny in air that was originated more than a decade ago to satisfy a specific need in the uranium mining industry. One WL is defined as any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.[1] The use of this term and its definition has recently been found in official regulations and publications of federal agencies.[2,3,4] The definition ought to be revised and another name adopted before the trend becomes completely irreversible.

Deficiencies of present definition

1. The use of more than one significant figure in setting radiation protection guides is not justified on the basis of present knowledge of biological effects nor on the basis of the precision of exposure evaluation. The numerical value of the "working level" is derived from the alpha energy released by the complete decay of the short-lived progeny in equilibrium with an airborne ^{222}Rn concentration of 100 pCi/liter. The value of

1. USPHS Publ. 494, Control of radon and daughters in uranium mines and calculations on biologic effects, 1957.
2. Department of Labor regulations, 41CFR50-204.321 (a), Fed. Reg. 32: 8412, June 13, 1967.
3. Federal Radiation Council, Radiation protection guidance for federal agencies - memorandum for the President, July 21, 1967, Fed. Reg. 32:11183, August 1, 1967.
4. FRC Report No. 8 (revised), Guidance for the control of radiation hazards in uranium mining, 1967.

100 pCi/liter was initially selected as the most appropriate order of magnitude to consider in making dose calculations. Clearly, a greater degree of precision was not intended. In addition, all other concentration guides or limits for airborne radioactivity are stated with only one significant figure.

2. The unit is not defined accurately in terms of the specific radon progeny of concern; namely, the short-lived daughters. As defined, the "working level" would include the alpha decay of RaF (^{210}Po). A recent report of an NAS-NRC Advisory Committee (5) has, however, included the words "short-lived daughters" in the definition of WL as used in that report.

3. The word "potential" is ambiguous and unnecessary. The potential, or latent, alpha energy exists only before the emission of the alpha particle; the "ultimate emission" is the kinetic alpha energy which is the quantity that is measured and which also produces the biological effect. Following the phrase "ultimate emission", the word "potential" seems to be redundant.

4. The term "working level", although now in common usage, has no physical basis and only minimal operational meaning. It is also rather absurd when applied to environmental concentrations of radon progeny where no occupational exposure is involved. A more descriptive name should be adopted which would be readily applicable to all situations involving atmospheric concentrations of radon progeny.

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5. National Academy of Sciences - National Research Council Advisory Committee from the Division of Medical Sciences, Radiation exposure of uranium miners, Federal Radiation Council, August, 1968.

Numerical value

The reduction of the numerical value of the radon progeny exposure guide to one significant figure is obviously appropriate. However, the particular significant figure to use is not so readily apparent. The value selected for use in a revised definition ought to be the one with the greatest significance and potential for continued use.

The simplest change that could be made would be to round off the present Working Level value to one significant figure, i.e. 1×10^5 MeV latent alpha energy per liter of air. However, since it is very probable that exposure control limits may eventually be set somewhat lower, it would seem advisable to incorporate a smaller numerical value into any new definition. A value small enough to permit the majority of exposures to be expressed in multiples of the basic unit, rather than in fractions of a unit, would have certain advantages for record keeping purposes. Also, until more precise information is available on biological effects, the connotation that any exposure to less than one unit is innocuous could be avoided.

The lower extreme to which one might go in defining the basic unit would be the natural background level for this type of exposure. A value of 1×10^3 MeV latent alpha energy per liter of air would closely approximate the average background exposure level. However, the use of this value in defining the basic unit would emphasize the fact that current exposures to miners are 100 or more times the average exposure to the public from the ambient atmosphere. Such an emphasis could be psychologically detrimental to the mining industry.

Perhaps the ideal numerical value to be used in a new definition of the exposure unit would be 1×10^4 MeV latent alpha energy per liter. This value is well below any limits presently being considered for exposure control regulations. Presumably, any significant occupational exposure could be expressed in multiples of this value, yet the majority would be expected to fall within one order of magnitude of the unit. Consequently, I would propose serious consideration of this value as the basis for a new definition.

Proposed unit definitions

A new unit for radon progeny concentrations in mine atmospheres must be defined explicitly, yet in as simple a manner as possible. The following suggestions are offered as possibilities having some merit:

1. The new unit could be defined as "any combination of RaA (^{218}Po), RaB (^{214}Pb), RaC (^{214}Bi) and RaC' (^{214}Po) in one liter of air that would emit, by complete decay through RaC' (^{214}Po), a total alpha energy of 1×10^4 MeV." This definition is worded in such a manner that it definitely refers to a concentration of airborne materials.

2. The unit could be defined as "1×10^4 MeV of latent alpha energy that would result from the decay through RaC' (^{214}Po) of the radon progeny contained in one liter of air." Although the radon progeny concentrations involved would be the same as in the first definition, the wording of this second definition emphasizes the latent energy concentration rather than the materials concentration.

Other air concentration units

1. The term Maximum Permissible Concentration (MPC) used by health physicists would be confusing since all other MPC's are expressed in units of μCi/ml of air. Also, this term implies a threshold, below which the exposure is innocuous; this may or may not be true.

2. The term Threshold Limit Value (TLV) used by industrial hygienists is even less satisfactory because of the definite implication of a biological response threshold.

3. The term Radioactivity Concentration Guide (RCG) introduced by the Federal Radiation Council is much preferred for most applications. However, the FRC definition of the RCG is expressed in terms of whole body or organ doses specified as Radiation Protection Guides.[6] Lung models, alpha exposure dosimetry, and epidemiology of lung cancer in uranium miners have not yet been developed to the point where a definite relationship between inhalation exposures and organ doses can be accurately inferred. Therefore, this terminology would also have misleading implications if applied to radon progeny concentrations in mines.

Proposed unit names

Since a change is proposed for the numerical value, as well as for the language defining the unit, a different name for the unit should be adopted to emphasize the revised definition and to avoid ambiguities. A name or acronym directly related to the physical basis or the unique operational applications of the unit would be most useful.

6. FRC Report No. 1, Background material for the development of radiation protection standards, 1960.

Any new name selected should not be restricted in its applications by referring to mines or underground exposures directly. The following possibilities are offered for consideration:

1. Radon Progeny unit (RP). This name has the advantages of referring directly to the contaminants of interest and of following precedents established by other terms in common usage, e.g. "Strontium Unit" and "Tritium Unit."

2. ABC unit (ABC). This name has the advantage of being somewhat an acronym for RaA, B and C and, therefore, a constant reminder of the physical meaning of the unit. Also, it is not likely to be confused with any other units.

3. Alpha Aerosol unit (AA). This name relates directly to the source of the predominant inhalation exposures in mines, namely, the latent alpha energy carried on aerosols.

Cumulative exposure units

Consideration should also be given to the convenience of expressing cumulative exposures to individuals or groups as is presently done in units of Working Level Months (WLM) and Working Level Man-Months (WLMM). In addition, any cumulative exposure limits included in new regulations should be expressed to only one significant figure or order of magnitude. Limits stated as 3.6 WLM/year or 1.8 WLM/quarter are completely unjustified as well as being misleading. Such values imply that an individual's exposure can be documented to an accuracy of two significant figures; this is nonsense under present monitoring procedures. A limit expressed, for example, as 3.6 WLM/year also means that a legal violation has occurred if an individual's records indicate 3.7 WLM/year, whereas a record showing 3.6 WLM/year shows complete compliance with the regulations. If current monitoring methods are accurate to within 30% for cumulative exposures (which they may not be), a record indicating 3.6 WLM may actually reflect a true exposure anywhere in the range of 2.5 to 4.7 WLM. Permission to round off the cumulative exposure record to one significant figure at the end of each quarter should be included in the regulation.

MOTIVATION FOR EXPOSURE REDUCTION

Risk related monitoring

One of the goals for any radiation exposure control program should be to reduce all exposures to the lowest practical level, not merely below a legally permissible limit. Achievement of this goal requires a strong motivation on the part of employers of radiation workers. One method of providing some incentive for exposure reduction, while simultaneously improving the efficacy of the regulatory program, would be to require different degrees of monitoring for workers exposed to different atmospheric conditions. This concept of risk related monitoring would ease the burden of monitoring and record keeping for those employers who maintain working conditions at or below some predetermined risk level. Monitoring and record keeping efforts, as well as regulatory inspections, could be concentrated on the specific cases of greatest risk.

In large uranium mines, many miners spend the bulk of their work time in a few well-ventilated areas where radon daughter concentrations are relatively low and rather constant. Under such conditions monitoring requirements should be minimal. The presently used method incorporating spot air sampling and exposure time recording may be adequate. On the other hand, a majority of miners in small mines and at least a few in every large mine must frequently or occasionally enter areas with little or no ventilation control. These are the individuals on which exposure monitoring and control efforts should be concentrated. The precision of the spot air sampling-exposure time keeping method of exposure evaluation is highly dependent upon the variability of the exposure and the number of air samples evaluated. To a somewhat lesser extent it depends upon the detail to which exposure time records are kept. Occasional spot air samples and rough estimates of exposure times in unventilated areas are simply not adequate for monitoring short exposures in high and variable radon daughter concentrations.

An illustration of the application of risk related monitoring using the definitions and values contained in the proposed regulations would be:

Radon progeny concentration in area (WL)	Minimum frequency for determining WL concentrations	Minimum accuracy of exposure time records
Less than 0.3, relatively stable	Biweekly, or when significant ventilation changes are made.	Within one-half day per two weeks.
0.3 to 3, stable or variable to this level.	Once for each entry into the area.	Within one-half hour per day in which exposure occurs.
More than 3, stable or variable to this level.	Continuous during exposures.	Within five minutes for each period of exposure.

Personal monitoring devices

The ideal method for evaluating exposures to individuals who must work in areas of high and variable radon daughter concentrations would be to use individual continuous monitoring devices. One such personal monitoring system has been developed at Colorado State University.[7]

7. Schiager, K.J. and A. H. Dahl, Radon progeny inhalation study, COO-1500-5, Third annual progress report on USAEC Contract AT(11-1)-1500, Colorado State Univ., Ft. Collins, Colo., Feb. 29, 1968.

This system utilizes a small, battery powered air sampling pump worn on the belt, connected to a one-half inch diameter filter holder worn on the hard hat. The filter holder contains a thermoluminescent dosimeter that responds to the cumulative alpha particle energy emitted by radon daughters collected on the filter paper. As it is presently being used in field studies the system is sensitive enough to measure as little as 0.05 WLM exposure per month, but it can be made even more sensitive if necessary. The accuracy of the system is estimated to be well within ten percent in field use; the standard deviation for over one hundred laboratory tests was less than three percent.

Other personal monitors for airborne radon progeny exposures have been developed at New York University, Eberline Instrument Corp. and General Electric Company. Field evaluations of these devices are currently being conducted by the USAEC Health and Safety Laboratory. Although the test results may show that some devices are better than others, the findings will not alter the fact that personal monitoring devices have been developed and could be made commercially available very quickly if they were in demand.

The regulations pertaining to exposure monitoring should not specify one, and only one, monitoring method. Instead, the regulations should specify the conditions under which monitoring is required and the degree of accuracy required under various circumstances. The regulations should be flexible enough to permit and encourage development and use of improved monitoring techniques.

Respiratory protection

Extensive testing programs conducted by Colorado State University (8), Los Alamos Scientific Laboratory (9) and others have conclusively demonstrated the protective value of half-mask respirators equipped with appropriate filter cannisters. The difficulties in implementing this form of exposure reduction are first, to motivate miners to use respirators, and second, to determine what, if any, credit to allow for the use of respirators in exposure evaluation. These two problems are closely related since the incentive for respirator use would be provided by the credit for exposure reduction.

In order to allow a valid credit for exposure reduction through respirator use, a method must be available for evaluating the actual internal exposure of an individual miner. Colorado State University has been investigating the possibilities of bioassay methods for evaluating radon progeny inhalation exposures to uranium miners (10). Although we cannot yet state the sensitivity or reliability of bioassay exposure monitoring, we are optimistic about its potential value. We are currently conducting a field test of exposure evaluations using bioassay methods as compared with the direct personal

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8. Martz, D. E., Respiratory protection for uranium miners, COO-1500-9, Special report on USAEC Contract AT(11-1)-1500, Colorado State University, Ft. Collins, Colo., June 1, 1968.
9. Johnson, K.J., Respiratory protection for uranium miners, The Atom, 5 (No. 11):12-19, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, November, 1968.
10. Gotchy, R.L., A survey of bioassays for uranium miners, COO-1500-10, Special report on USAEC Contract AT(11-1)-1500, Colorado State University, Ft. Collins, Colo., June 1968.

monitoring method under a contract (PH-43-68-1326) with the U.S. Public Health Service. Forty miners, working in four mines in the Grants, New Mexico area, are participating in the one-year study.

Regulations should be written in such a manner that credit for exposure reduction through the use of respirators, or any other technique, would be allowed if reliable data were available to substantiate the claim for the credit. Such a provision in the regulations might provide some incentive for development and documentation of additional exposure reduction methods.

APPROPRIATE REGULATIONS

Radiation exposure regulations for uranium mining should provide positive incentives for exposure reduction and place emphasis on the significantly high exposure situations. Regulations should eliminate excessive risks to individual miners without unnecessarily penalizing mining companies that have already gone to great lengths to reduce exposures.

Smoking prohibition

There is strong statistical evidence that cigarette smoking is synergistic in the production of lung cancers in uranium miners (5). Regulations prohibiting smoking underground could conceivably reduce the total cigarette consumption among uranium miners; this action alone might substantially reduce the risk of lung cancer in uranium miners.

Units and numerical values

Regulations should be based on definitions which are functionally and technically sound. The deficiencies of the Working Level unit have been pointed out, as have the invalidities of using two significant figures in regulatory limits.

External gamma-ray exposures

As part of the research conducted by Colorado State University, measurements were made of external gamma-ray exposures to uranium miners. These measurements indicated annual whole body doses to miners of one to four rems. Since these doses are additive to those resulting from inhaled radon progeny, the regulations should include provisions for monitoring and recording the external gamma-ray exposures. Permissible internal exposures should be adjusted to compensate for the variations in external exposures.

Flexibility of evaluation methods

Regulations should not specify the exact method to be used for evaluating radiation exposures. Such regulations would inhibit the development and application of improved monitoring methods. Only the performance requirements of radiation controls should be specified in the regulations.

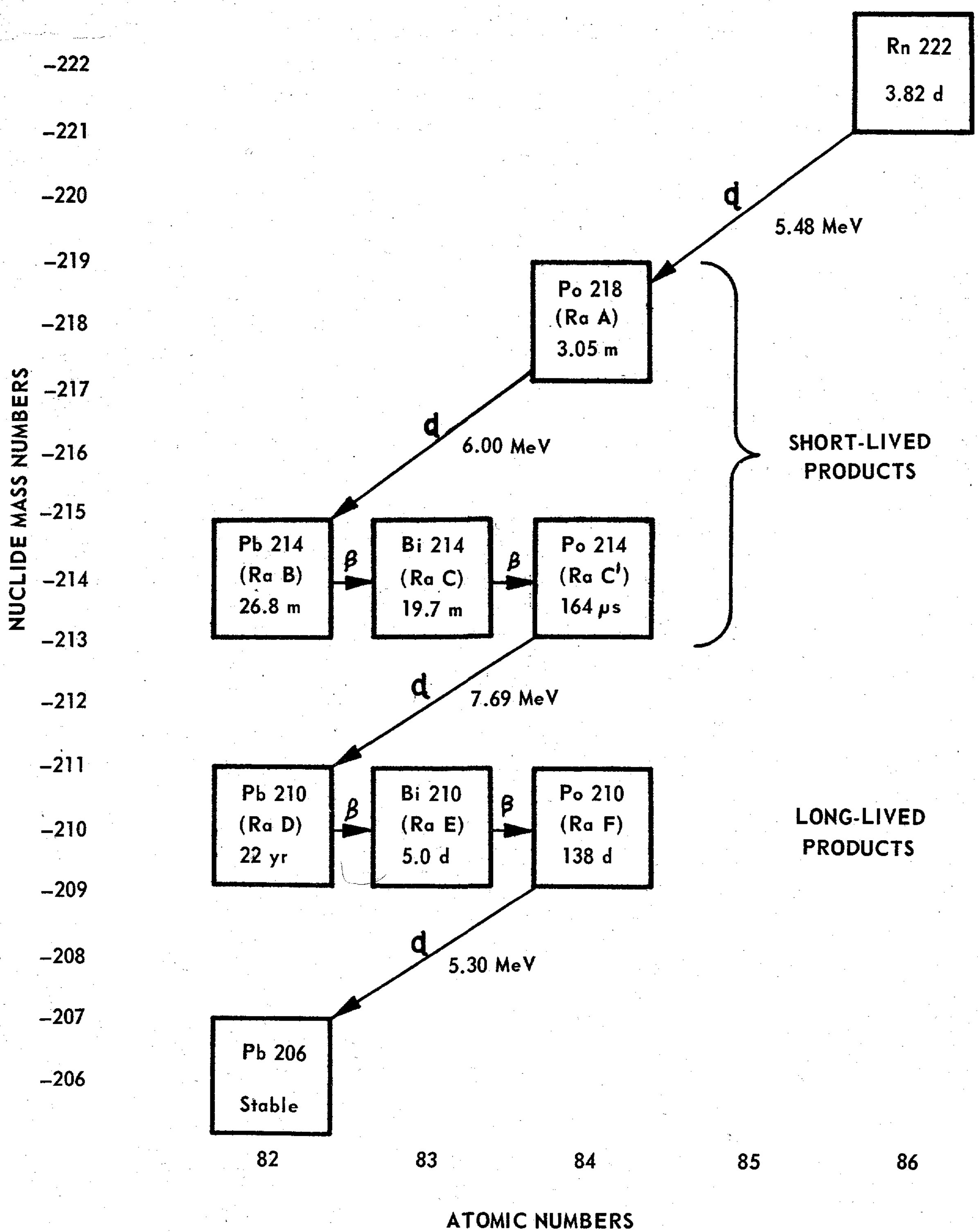
Exposure reduction incentives

In order to motivate both the mining companies and the individual miners to reduce radiation exposures, regulations should include:

1. provisions for risk related monitoring, i.e. monitoring requirements proportionate to exposure levels.
2. allowances for exposure reduction credit for the use of respirators if the exposure reduction can be documented.
3. provisions for transferring an individual miner's exposure record to successive employers.

Implementation of regulations

The proposed regulations (41 CFR 50-204.321) should not be implemented in their present form. Consideration should be given to the availability of adequate monitoring methods and to alternate possibilities for reducing the risk of lung cancer in uranium miners before excessively restrictive regulatory limits are imposed on mining companies.



RADON (222) DECAY SCHEME