



**International Conference  
on  
Occupational Radiation Safety  
in Mining**

October 14 - 18, 1984  
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**Abstracts**

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Occupational Radiation Safety  
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ABSTRACTS

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ABSTRACTS

Monday, October 15, 1984 - Session 3a 14:00-17:00  
VENTILATION/ENGINEERING

PILOT ALARA ANALYSIS APPLIED TO DOSE REDUCTION IN  
AN UNDERGROUND URANIUM MINE

BY: Denison/Rio Algom (Canada)

Radiation exposure regulations are implemented in Canada by the Atomic Energy Control Board (AECB). The AECB regulations are generally based on the recommendations of the ICRP. In November 1983, the AECB issued proposed new radiation protection regulations related to ICRP 26 recommendations for public comment. The proposed changes and the AECB regulations are extensive and include a specific requirement that "every licensee should establish, implement and maintain procedures designed to maintain doses of radiation as low as reasonably achievable, social and economic factors being taken into account." While the ICRP and others have published extensive philosophical discussions and idealized "practical" applications of the ALARA concept and how it should be applied, there are little, if any, published data discussing the application of ALARA to an actual uranium mine. Consequently, the difficulties in actually doing an ALARA analysis for an operating uranium mine are largely unknown and a matter of speculation. Recognizing these uncertainties, Denison Mines Limited and Rio Algom Limited retained SENES Consultants Limited to prepare a study to identify the possible practical difficulties involved in applying ALARA to the underground uranium mine environment. The study focussed on the reduction of exposure to radon (and thoron) daughters by increased ventilation. The increased costs of ventilation were compared to potential collective dose reductions, both for specific worker categories and for the entire underground mining population. The resultant "alphas" (incremental cost/dose saved) were compared to published values from radiation and other occupational protection sources. Data requirements for doing the ALARA analysis, and the findings of the study are discussed.

RADIATION SAFETY ASPECTS OF OCCUPATIONAL AREAS  
AT A BRAZILIAN OPEN-PIT MINE

BY: S.M. Carvalho, C.L. Mouço, J.S. Estrada, C.V. Ney  
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Comissao Nacional de Energia Nuclear, Rio de Janeiro, Brazil

The large uranium reserves and the ongoing Brazilian Nuclear Industry have led to the exploration of several uranium mining sites. The only commercial exploration site at present is located at the CIPC (Complexo Minerio-Industrial do Planalto de Poços de Caldas) where the uranium is mined open-pit.

The health hazards associated with uranium mining has brought to the attention of the Brazilian Nuclear Energy Commission the necessity of a close surveillance of the occupation areas at the CIPC.

This paper discuss the radiation safety aspects of open-pit mining in Brazil and presents results of exposure rate measurements at points located at different work-front sites, primary crushing, static leaching sites and ore storage patio. Results of surface contamination and air monitoring in the hauling trucks and area control cabs are presented. Routine difficulties in trying to comply with the radiation safety procedures required is discussed and suggestions presented.

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A DYNAMIC APPROACH TO THE IMPLEMENTATION OF  
THE OPTIMIZATION PRINCIPLE IN URANIUM MINES

BY: N. Fourcade, P. Zettwoog  
IPSN/DPT/SPIN/LRPM  
Fontenay-aux-Roses, France

The problems which arise from the implementation of the principle of radiation protection optimization in uranium mines are studied. Various attempts to apply this principle to some limited extent have already been presented in the literature. It is shown that the particular decision-making context characteristic of uranium mining necessitates a different approach from that which may suffice for the other stages of the nuclear fuel cycle.

The characteristics particular to the decision-making context in uranium mines are the following:

- The decisions must be made for an uncertain rather than for a deterministic future. These uncertainties concern all the parameters of the orebody which will influence the extraction conditions as well as the level of irradiation.
- Methods of dynamic programming must be considered, that would take into account normal evolution and unforeseen events which can occur between the beginning and the end of the mining operation.
- Given the fact that the principle of limiting individual doses seems to be hard to respect in the mines, not only a term proportional to the collective dose must be introduced into the expression of the collective detriment, but also a term which takes the distribution of the individual dose into account.

Such an optimization procedure which takes into account these particularities is progressively being implemented in French mines. The consequences of such an optimization procedure on the organization of the monitoring system in underground stopes is described herein, in view of an application in the short or medium term in mines already in existence, or in the long term for previsions studies of future mining operations.

CONTROL OF RADIATION HAZARDS IN URANIUM EXPLORATION

BY: H.A. Hussein, A.M. El-Naggar, M.A. Hassan, F.M. El-Assaly, A.T. Abdel-Fattah  
Nuclear Materials Corporation  
CAIRO - Egypt

Uranium exploration activities in Egypt started in 1956, using various methods and techniques. This resulted in the discovery of several occurrences of potential uranium ore deposits.

During the past few years, several exploration galleries were excavated into granitic terrain of very rough topography to explore uraniferous veins. These veins carry secondary uranium minerals on the surface and disseminated and massive pitchblende were recorded in localised spots in some of the veins underground.

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In parallel with these exploration activities, bench and pilot scale experiments were carried out on various radioactive materials which constitute potential sources of uranium. These are mainly granitic rocks, sandstones and shales, phosphorites and monazite.

These activities were simultaneously associated with the necessary measures to control radiation hazards according to the concept of justification and optimization of radiation protection according to the ICRP system of dose limitation and risk assessment.

Field studies of uranium exploration sites and ancillary laboratories were performed in the light of this system. The data obtained shows that radiation hazards are mainly due to:-

- 1) daughter products of inhaled radon and thoron in poorly ventilated sites and closed areas.
- 2) inhalation of radioactive dust particles.
- 3) external exposure mainly from radioactive dust contamination.

Protection measures implemented constitute the following aspects.

- 1) Continuous monitoring of radon and dust particles.
- 2) Personnel monitoring of all workers using various methods according to working conditions, and assessment of radiation dose.
- 3) Effective ventilation of underground working sites as well as closed spaces.
- 4) Prohibition of work in areas of high radiation background.
- 5) Medical surveillance of all workers and periodic follow up.

This presentation reports the results obtained from such studies over a period of three years.

#### RADIATION PROTECTION AT A HIGH GRADE URANIUM MINE

BY: Tim Meadley, Kevin Bundy, Wanda Schidlowsky  
Amok Ltd., Saskatoon, Saskatchewan, Canada

Since early in 1980, Amok Ltd., on behalf of Cluff Mining has been operating uranium mining and milling facilities at Cluff Lake, Saskatchewan. Initial operations have been concerned with the extraction and processing of material from the D orebody that averaged approximately 7% uranium.

In order to ensure adequate standards of health and safety, the company undertook a number of innovative programs in the area of radiation protection. Experience has shown that some of the programs that were initiated were very effective, others required modification during implementation and that a few were superfluous.

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Results from the company's personal and work environment monitoring program have shown that, provided adequate precautions are taken, increase in ore grade does not necessarily mean a corresponding increase in employee radiation exposures.

Mining of other high grade orebodies in Saskatchewan is now being contemplated, and the Amok experience will provide useful data for the design and evaluation of radiation protection programs at future high grade facilities.

#### RADON AND RADON DAUGHTER CONCENTRATIONS OVER AN EXTENDED URANIUM ORE BODY

BY: (1) R.S. O'Brien, S.B. Solomon, K.H. Lokan, T.H. Gan, L.J. Martin,  
K.N. Wise and (2) V.A. Leach  
(1) Australian Radiation Laboratory, Yallambie, Australia  
(2) Northern Territory Dept. of Health, Darwin, Australia

A 21m tower has been set up over a shallow, extended uranium ore-body near Yeerlirrie, Western Australia. The tower carries instruments to measure wind speed and direction, temperature, radon concentration and radon daughter concentration, with the aim of correlating radon and radon daughter concentrations with local meteorological parameters. The ore-body is situated in a wide, shallow valley in a semi-desert region, where earlier measurements indicated that, during the winter months, stable nocturnal inversions, accompanied by high radon and radon daughter concentrations, occurred frequently.

Data acquisition is carried out under control of a micro-processor, which averages the data from each instrument over 20 minute intervals and records them on magnetic tape.

The paper presents results from the study, together with a discussion of possible mechanisms controlling the atmospheric concentrations of radon and radon daughters at the measurement site.

Monday, October 15, 1984 - Session 3b 14:00-17:00  
INSTRUMENTATION

#### RANDOMIZATION OF GRAB SAMPLING STRATEGIES FOR ESTIMATING THE EXPOSURE OF URANIUM MINERS TO RADON DAUGHTERS

BY: (1) T.B. Borak and (2) R.F. Holub  
(1) Department of Radiology and Radiation Biology, Fort Collins, Colorado  
(2) U.S. Department of the Interior, Bureau of Mines, Denver, Colorado

In most underground uranium mines in the USA the integrated annual exposure to radon daughters is determined by combining periodic grab samples of working level with time of occupancy. This can lead to considerable uncertainties. One important consideration is the systematic bias introduced if the grab samples are taken at the same time each day or during periods immediately following the repair of a faulty ventilation system. Statistical procedures are discussed which randomize the time between samples for each location. Complete randomization of all sample times is often not feasible due to manpower and budget considerations. Methods which compromise true randomization without introducing bias are being investigated.



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THE DEVELOPMENT, INTRODUCTION AND EARLY OPERATING EXPERIENCE OF A  
LARGE SCALE EXTERNAL GAMMA MONITORING PROGRAM IN CANADIAN URANIUM MINES

BY: R.P. Bradley, D. Grogan  
Radiation Protection Bureau  
Department of National Health and Welfare, Canada

At a meeting of representatives of the Atomic Energy Control Board, uranium mining company managements, mine employee organizations, provincial ministries of health and labour and the Department of National Health and Welfare (NHW), in August 1979, it was unanimously agreed that the Radiation Protection Bureau of NHW would undertake to develop a dosimetry system for the assessment of exposures to uranium mine personnel from external gamma ray sources. This paper is divided into five sections: conceptualization and problem definition, development, implementation, "shake-down", and routine operation. Each section addresses the problems and solutions encountered during the various phases of the development. Manpower requirements, capital costs and specific methods of operation are outlined. Problems in dosimeter design, holder construction and distribution logistics are explained along with the chosen solutions. Finally, impressions of potential areas of further refinements as the system settles down to routine operation are presented.

LONG TERM MEASUREMENTS OF WL-LEVELS IN METAL MINES  
BY USING THE ASS-SYSTEM AND HCS-SYSTEM

BY: T. Domanski, W. Chruscielewski  
Institute of Occupational Medicine  
Poland

In Polish zinc-lead ore mines the system of measurements of alpha potential energy was introduced in 1977. This system, named Helmet Cassette System /HCS/, is based on the use of track-etch detectors type LR-115 which are worn by the selected groups of miners on their helmets. Since 1981 another system, named Air Sampling System, has been introduced in parallel. It has been based on the use of the portable instant working level meter of WL's. The measurements in ASS are done by the specially trained technicians from ventilation services of every mine. The measurements have been done on the typical work-places as well as on the transportation roads and cross-adits in mines.

About 300 measurements in HCS and 200 measurements in ASS are usually done yearly in every mine. The Institute of Occupational Medicine in Lodz supervises both the systems, directly reads the track etch films, and computes the results. The comparison of the results of alpha potential energy measurements carried out in 1981 and 1982 shows that the ratio of mean values of annual concentrations for ASS/HCS is 3-5 in the majority of mines. Assuming that HCS measures the mean values more accurately, it suggests that generally ASS overestimates the miners' exposures. Also, the obtained results offer an additional argument for the use of radon daughter individual dosimetry in the assessment of miners' risk.

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MEASUREMENT OF TEMPORAL VARIATIONS IN  
RADON PROGENY WORKING LEVELS IN MINE ATMOSPHERES

BY: (1) V. Roze, R. Raz (2) J. Bigu  
(1) alpha NUCLEAR, Mississauga, Ontario  
(2) Energy, Mines and Resources Canada, Elliot Lake, Ontario

A radiation monitoring system is described which measures radon progeny Working Levels as a function of time. A portable programmable microcomputer is incorporated in the system to analyze data from a time-integrating WL monitor. Polynomial filtering is used to deconvolve the data and allow short term fluctuations in WL to be observed, as well as correcting for the time lag inherent in such devices.

The system can be used to monitor work sites for ambient radiation levels; personal monitoring is also possible because of the compact dimensions. Data obtained with the system, when correlated with ventilation and fan conditions and other mine variables, can provide valuable information in analyzing occupational environments with a view to minimizing personnel exposure and optimizing ventilation conditions and energy management.

The applications, needs and benefits of the system are described together with a description of the mathematics and theoretical basis. Field data are reported showing practical applications in mining environments.

COMPARATIVE TESTS OF RADON- AND RADON DAUGHTER DETECTION  
SYSTEMS UNDER SIMULATED ENVIRONMENTAL CONDITIONS

BY: F. Steinhausler, F. Daschil, P. Pfligersdorffer  
University of Salzburg  
Salzburg, Austria

Radon- and radon daughter-monitors have to be able to function even in hostile environments, such as mining and milling operations. These conditions can range from high temperature/low humidity to low temperature/high humidity.

Besides withstanding these environmental stresses the instrument response should be specific in case of the simultaneous presence of radon 222- and radon 220 (thoron) in the atmosphere, since the latter can represent a major component of the total occupational exposure.

Commercially available instrumentation can be categorized as either basically monitoring radon gas or radon daughter products. Therefore in this study two such instruments were selected for the tests: an EDA-RD200 radon monitor and PYLON-WL-1000C radon daughter analyzer.

These instruments were exposed to the extreme environmental conditions described above by using a dual-walk in test chamber system. In these chambers temperature, relative humidity, radon-, thoron- and decay product concentration were kept at preset defined levels. The operating characteristics of both instruments were studied with respect to reproducibility and reliability for both radon- and thoron atmospheres. Furthermore, the variation due to using different analytical methods (ROLLE, modified KUSNETZ and modified TSIVOGLU) under these conditions was investigated in a sensitivity analysis.

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AERODYNAMIC PARAMETER DETERMINATION IN INLET ORIFICE  
OF CEA PERSONAL ALPHA DOSIMETER

BY: K. Yoshida  
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Saskatoon, Saskatchewan, Canada

The examination of aerodynamic parameters of modified CEA personal alpha dosimeter was made by using nominal values (specifications) supplied by the manufacturer in order to determine the geometry and the Reynolds number of inlet orifices, the collection efficiency of the filter affected by the face velocity, the hygroscopic property of filter material under normal operational condition. A test dosimeter in operational condition was placed in an aerosol chamber to which test aerosols of non-radioactive but similar size characteristics to alpha-emitting aerosols previously found in actual mining environment were introduced by using a condensation type mono-disperse generator. The trajectory of test aerosols in the vicinity of dosimeter inlet orifices was obtained graphically by using the flow visualization technique. The shape and size of aspiration zone of dosimeter varied slightly with the concentration of test aerosols; however, the diameter of spherical eddy created around the inlet orifice was 10 cm at the concentration of 10 mg/m<sup>3</sup> of test aerosol. A practical concept of breathing zone tentatively proposed by occupational health practitioners is a sphere centered at the nostrils having a diameter of 60 cm at moderate rate of respiration. The aspiration zone of CEA dosimeter determined would be located too far from the edge of breathing zone without overlapping if the dosimeter is worn at the waist as recommended. The presently recommended location of the dosimeter may not be for an adequate representation of inhalation exposure in this view. However, the present location near the groin region may be still justified since the dosimeter is intended for simultaneous determination of alpha and gamma dose.

Monday, October 15, 1984 - Session 3c 14:00-17:00  
DOSIMETRY

A STUDY OF THE DOSE CONVERSION FACTORS FOR INHALATION RISK  
ASSESSMENT FROM RADON DAUGHTERS IN MINE ATMOSPHERE

BY: M.C. Subba Ramu, K.G. Vohra  
Bhabha Atomic Research Centre  
Bombay, India

With the increasing importance given to dosimetric methods of evaluation of inhalation risk to uranium mine workers for obtaining a better insight into the dose-effect relationship, it becomes necessary to look into the various aspects of the assessment of lung dose from radon daughter products in the uranium mine atmosphere. Epidemiological evidences for occurrence of cancer in the bronchial region of the lung of uranium mine workers emphasises that bronchial dose should be considered for the dose-effect studies. Calculations of activity to dose conversion factors are based on the results of the studies of the unattached and attached fractions of radon daughter products. The nature, size distribution and concentrations of aerosols that carry the daughter products into the lung are considered in the calculations. Deposition and clearance rates of the aerosols are estimated using either the Wiebel or the improved Yeh-Shum model. The basal cells of the bronchial epithelium are considered as the critical target.

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The dose conversion factors estimated by various investigators vary from 0.2 to 15 rad/WLM. The same estimated by us taking into considerations the hygroscopic nature of the carrier aerosols and the energy dependent regional tissue masses is 0.9 rad/WLM. Based on these estimations, the dose equivalent limits for uranium mine workers have been computed for both the stochastic and non-stochastic effects. Their relevance in controlling the radon daughter exposure to the mine workers is described. Further the significance of a proper rad to rem conversion factor for uranium mine workers based on epidemiological results of lung cancer is discussed.

"CANADIAN AND U.S. APPROACHES TO OCCUPATIONAL HEALTH REGULATIONS"

BY: M.J. Wright  
Industrial Hygienist  
United Steelworkers of America

Canadian and U.S. approaches to establishing occupational health regulations are compared and contrasted. In particular, the recent U.S. OSHA lead standard and the Canadian AECS proposals for uranium mines are used as case studies. The paper compares the standard-setting process in the two countries with respect to risk assessment, the role of feasibility considerations, public participation, regulatory review of government bodies beyond the standard-setting agency, and the right of legal challenge.

THE UNITED STATES URANIUM REGISTRY TISSUE PROGRAM: AN UPDATE

BY: Robert H. Moore, M.D.  
Hanford Environmental Health Foundation  
Richland, WA 99352

The U.S. Uranium Registry was inaugurated by the United States Department of Energy in 1978. A tissue donation program was established in 1979, and a report on the design and concept of this program was presented in 1981.

Since then the location and methods of tissue analysis have changed. Analysis of specimens obtained at surgery and at autopsy from individuals occupationally exposed to uranium was begun in 1981.

This update report will describe current tissue analytical techniques, and the concept of dual analysis of the same tissue by different techniques. The report will also outline progress on target population enrollment, and identify new target populations with their anticipated importance.

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"ARE THE CURRENT DOSE LIMITS FOR URANIUM MINES TOO HIGH?"

BY: M.J. Wright  
Industrial Hygienist  
United Steelworkers of America

In the spring of 1984, the USWA and other unions petitioned the Atomic Energy Control Board of Canada for a general lowering of occupational radiation dose limits. This paper discusses the evidence supporting lower dose limits for uranium miners, along with the limitations of that evidence. The issue of regulatory policy in the face of scientific uncertainty, and feasibility problems with respect to lower dose limits, are also discussed.

THE CONSEQUENCES OF THE LATEST ICRP RECOMMENDATIONS ON  
A REVISION OF PUBLICATION 24

BY: H. Jammet and R. Coulon  
Institut de Protection et de Sûreté Nucléaire  
Fontenay-Aux-Roses (France)

In 1976, ICRP issued its Publication No.24, entitled "Radiation Protection in uranium and other mines" which discusses the principles of protection of uranium miners and the methods of application of these principles.

Since 1976, ICRP has published new recommendations, notably:

- in its Publication 26, which deals with new general principles of radiation protection,
- in Publication 32, where new values for the dose limits related to inhalation of  $^{222}\text{Rn}$  decay products are recommended,
- in Publication 35, which discusses the general principles of monitoring for workers,
- in Publication 37, which treats in a detailed way the cost-benefit analysis procedure to be applied when optimizing the level of protection.

Since 1976, experience has also been accumulating on the ways and means leading to the improvement of the individual and collective levels of protection for workers in uranium mines, especially in the field of dosimetry. Optimization methods are now applied in uranium mines to a large extent and individual exposures are known with accuracy in the countries where miners are equipped with personal dosimeters both for external and internal irradiation.

In view of the particular importance of uranium mining in the nuclear fuel cycle, the ICRP has found it necessary to undertake a revision of Publication 24. In this document, new limits, such as the secondary limit of 0.02 Joule for the potential alpha energy intake of  $^{222}\text{Rn}$  decay products in a year, are introduced as well as guidance on how the level of protection can be optimized.

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PROBLEMS IN SETTING AND APPLYING LIMITS FOR  
OCCUPATIONAL EXPOSURE TO RADON DAUGHTERS

BY: W.R. Bush  
Atomic Energy Control Board  
Ottawa, Canada

If the radiation protection of uranium miners is to be comparable to the protection of other radiation workers, a radon daughter intake limit is needed which is equivalent in terms of health risk to the 50 mSv annual limit on effective dose equivalent (EDE). However, the exact correlation between radon daughter intake and EDE is uncertain due to uncertainties in the underlying epidemiological information. Moreover, the radon daughter limits that have been based on epidemiological studies of uranium miners are in fact limits on radon daughters plus uncertain proportions of gamma radiation, radon, uranium, thorium, thoron and thoron daughters. Consequently, care is required when applying such "radon daughter" limits within the EDE framework, in order to prevent double counting of the dose contributions from these other sources.

The ICRP has recommended a radon daughter limit based on both the epidemiological evidence and the limitation of the calculated dose to the lungs. Uncertainties exist in both approaches, but instead of choosing one uncertain approach rather than the other, the ICRP has recommended a limit that can be supported by both approaches.

The advantages and limitations of applying a radon daughter limit within the EDE framework, as well as the uncertainties in the dosimetric and epidemiological approaches, are discussed in the paper. Additional issues raised during the public consultation period by labour and management are also discussed, and the AECB approach to a practical solution is explained.

Tuesday, October 16, 1984 - Session 5a 09:30-12:00  
VENTILATION/ENGINEERING

REMOVAL OF AIRBORNE THORON(RADON) DAUGHTERS ON MINE WALLS AND  
OTHER SURFACES BY CONVECTIVE DEPOSITION AND ELECTROSTATIC PLATE-OUT

BY: J. Bigu  
Energy Mines and Resources, Canada  
Elliot Lake, Ontario

Experimental data on thoron(radon) daughter plate-out phenomena on walls by convective and electrostatic deposition are presented. Experiments were carried out in underground uranium mines and in a large ( 26 m<sup>3</sup>) radon/ thoron calibration facility. Measurements were conducted under a wide range of environmental conditions including relative humidity (30-90%), temperature (14-25°C), aerosol concentration (1 x 10<sup>3</sup> - 2 x 10<sup>5</sup> cm<sup>-3</sup>), and air velocity (0 - 1.2 m/s). Experimentally determined radon and thoron daughter deposition velocities were in the range of 0.06-0.6 cm/s. These values are substantially lower than theoretical estimates by several authors on which plate-out calculations are based.

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The effect of an electrostatic field on the plate-out of thoron daughters has been investigated in a radon/thoron calibration facility. DC voltages ranging from 0 Volts to  $\pm 1000$  Volts were applied to aluminum metal mesh electrodes. Measurements show quite a substantial reduction in the thoron daughter Working Level, about a factor 2 to 4, when a voltage between -300 V and -1000 V is applied to the metal mesh. Experiments were preferentially conducted at low aerosol concentrations, i.e.  $1 \times 10^3$  to  $3 \times 10^3$  cm<sup>-3</sup>. Preliminary studies in an underground uranium mine also shows a similar phenomenon as that indicated above.

The studies described here are relevant for realistic determination of airborne radiation levels in underground uranium mines, particularly Canadian mines where the presence of thoron daughters is appreciable.

PRACTICAL APPROACH TO RETROSPECTIVE ESTIMATION OF RADON DAUGHTER  
CONCENTRATION IN THE UNDERGROUND MINING ENVIRONMENT

BY: A.B. Dory and D.A. Corkill  
Atomic Energy Control Board  
Ottawa, Ontario, Canada

The epidemiological approach to assessment of health effects attributable to radon daughter inhalation by underground miners is still the most reliable method of determining the risk per unit of exposure. Several groups of miners have been studied in the past. The common element of all studies is a very poor quality of the exposure data. Very limited number of radon daughter concentration measurements were taken in earlier years. The exposures of the study populations were therefore, in most cases, just crude estimates.

The presence of radon daughters in the underground mine is determined by the tectonic, mineralogical, hydrological and mining conditions. However, their concentration in the underground mine environment is mainly dependent on the ventilation.

The authors have reviewed different recent attempts to estimate the possible past ranges of radon daughter concentrations in the mines based on the assessment of the better documented ventilation conditions existing at that time. The use of mathematical ventilation models and computer utilization for this purpose was explored.

This paper provides an outline of procedures and methods which could be used to estimate the possible ranges of radon daughter concentrations in any mine, based on known ventilation data and limited number of measurements of radon daughter concentrations.

Practical examples of estimation of ranges of radon daughter concentrations are also provided.

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CHARACTERIZATION OF RADIOACTIVE LONG-LIVED DUST  
PRESENT IN URANIUM MINES AND MILLS ATMOSPHERES

BY: P.J. Duport, E. Edwardson  
Canadian Institute for Radiation Safety  
Elliot Lake, Ontario, Canada

Samples of uranium mines and mills atmospheres have been taken by means of open face filters and multi-stage cascade impactors. Open face filter samples have been analysed for total mass and alpha activity and for identification of alpha emitting radionuclides in long-lived dust. Dust collected on the stages of the cascade impactor has been analysed for size distribution, and for the distribution of specific radionuclides per class of dimension. In underground operations, both mass and activity follow a log-normal distribution, in which 50% to 80% of the particles collected have a Mass Median Aerodynamic Diameter (MMAD) smaller than 10  $\mu\text{m}$ , with a geometric standard deviation of about 5. The total dust concentration ranges from 100 to 3000  $\mu\text{g}/\text{m}^3$  of air, the gross alpha activity concentration ranges from 7 to 400  $\text{mBq}/\text{m}^3$  of air, and it has been observed that a high fraction of the total alpha activity is emitted by Radon gas and its decay products. The activity ratio of Po 218/Rn 220 can reach 70%, indicating a very low de-emanation rate of radon gas, even in small ore dust particles. It also appeared that radon daughters collected at the same time as mineral dust, show in the alpha counts as Po 210, calling for a careful interpretation of the data. About 50% of the total energy delivered by alpha particles emitted by a sample of "long-lived dust" is given off by the elements U 238, U 234, Th 230 and Ra 226. In the mills, alpha spectrometry analysis clearly shows two areas: ore processing (crushing, leaching) where all the alpha emitting elements of the uranium decay chain are present in the sample, and the yellow-cake area, where only the two peaks U 238 and U 234 are detected. Mass and total alpha activity concentrations in mills' atmosphere range from 100 to 4000  $\mu\text{g}/\text{m}^3$  and 15 to 800  $\text{mBq}/\text{m}^3$  of air respectively.

RECREATING AND MEASURING THE UNDERGROUND ENVIRONMENT  
OF THE LATE 1950'S

BY: A.G. Scott  
DSMA ATCON Ltd.  
Toronto, Ontario, Canada

The underground uranium mining environment of the late 1950's was recreated with respect to mining and local ventilation methods in a development heading at an Elliot Lake mine. Extensive measurements were made of dust, and radon plus thoron daughter concentrations, which were compared with the predictions of a detailed radon/thoron daughter computer model. Daughter production and removal rates derived from this study were compared with published values.

The WL values measured, and those predicted by the computer model for different working conditions and geometries were compared with those observed in the work place during the late 1950's. The conclusions of the study are presented.



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RADON EMANATION AT THE MUELLENBACH RESEARCH URANIUM  
MINE AND ITS EFFECTS ON VENTILATION PLANNING

BY: Reimk, M. Thome, W. Haupt  
Federal Republic of Germany

In uranium mining one has to cope with the ordinary risks of mining and the additional risk of radiation exposure by radon gas and its short-lived daughter products. The radon daughters are inhaled by the mine workers and partly deposited in the lung thereby causing a health hazard.

The main objective of the research project was to investigate and develop methods at the Muellenbach test mine which allow optimal protection against radon and its daughter products considering both economical and mining aspects. Theoretical models as well as investigations in the laboratory and underground have shown that good ventilation offers an effective protection against radon and its daughters.

Other methods such as wetting of broken rock and variation of the blasting procedure as well as the application of positive ventilating pressure were of minor influence on radon emanation. The sealing of rock surfaces showed satisfactory results in laboratory tests, however underground its application appears to be limited and unsuitable for stoping operations.

The research work done has shown that calculation models developed are of practical value for the determination of radon and its daughter concentrations as well as for mine ventilation planning.

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INSTRUMENTATION

CALIBRATION OF THE AIRBORNE RADON DAUGHTER MONITOR

BY: Martti Annanmäki  
Institute of Radiation Protection  
Helsinki 10, Finland

The calibration of a radon daughter monitor involves problems that are often neglected in published papers on radon daughter measurements. Consequently radon daughter levels measured in different countries may vary considerably due to improper calibration procedures. This paper describes four different methods of determining the efficiency of a windowless radon daughter monitor. The function of the monitor is based on silver activated zinc sulphide. The airborne radon daughters are collected on a glass fibre filter. One calibration method is the conventional method using a calibrated Am-241 source. Because the active area of the source was smaller than the detector active area, the efficiency was determined by taking measurements at a sufficient number of positions of the source relative to the detector. Three methods use calibrated reference instruments: a Ge gamma spectrometer, an alpha spectrometer and a liquid scintillation counter. Each of the four determination methods gave about the same efficiency for the monitor to be calibrated. The determination of the efficiency of a radon daughter monitor which has an aluminum-foil on the zinc sulphide is also presented.

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IN-MINE EVALUATION OF CONTINUOUS RADON AND WORKING LEVEL DETECTORS

BY: (1) M.R. Briggs, R.H. King (2) J.C. Franklin  
(1) Colorado School of Mines, Colorado, USA  
(2) U.S. Bureau of Mines, Spokane, Washington, USA

The U.S. Bureau of Mines, Spokane Research Center has developed a continuous radiation monitoring system for use in underground uranium mines. During the summer of 1983, the system was installed in a Southern Utah uranium mine. Tests were run to evaluate the continuous monitoring system by comparing data from the system with grab samples of both radon and working levels. The analysis of the data suggested other questions that were further tested at the Colorado School of Mines' Experimental Mine. The data from both experiments, analysis procedure, and final results are presented in this paper.

THE DEVELOPMENT OF TRACK ETCH DOSIMETERS  
FOR MEASURING RADON DAUGHTER EXPOSURES

BY: J.E. Gingrich, R.A. Oswald, H. Ward Alter  
Terradex Corporation, Walnut Creek  
CA U.S.A.

Significant progress has been made recently in developing a completely passive, integrating radon daughter dosimeter for personnel monitoring in uranium and other mines. These dosimeters appear to be much more acceptable to the mine operators and miners because of their small size and their elimination of complicated battery-powered pumps and electronic circuitry. The dosimeter concept is based on the well established track etch method for alpha particle detection. Preliminary tests in radon test chambers and uranium mines of different dosimeter designs has shown that the dosimeters can produce results comparable with the current grab-sample radon daughter detection methods. These dosimeters measure the integrated radon exposure and an appropriate working level ratio is applied to determine the radon daughter exposure.

Field tests of the dosimeter systems were conducted in underground uranium mines and in uranium mills in the U.S. and Canada. To provide comparative data, radon and radon daughters were determined simultaneously with other measurement techniques. These measurements also provided data on working level ratios which were used to calculate radon daughter exposures from the track etch dosimeters readings. In most instances the track etch dosimeters provided radon daughter exposures that were accurate to within  $\pm 20\%$  which is the same range as the statistical variation of the grab sampling method itself. The dosimeter test exposures ranged from about 0.1 to 0.5 working level months. Several minor operational problems were encountered in the early testing program and these were resolved in later tests.

The encouraging results from these tests suggest that this approach in measuring personnel radon daughter exposures is very promising and that it is accurate enough to be considered as an alternate to the currently used methods.

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THE DEVELOPMENT AND FIELD TESTING OF THE THERMOLUMINESCENT PERSONAL  
DOSIMETER FOR MEASURING EXPOSURE TO RADON AND THORON DAUGHTERS

BY: Li Hongquan, Pu Quangen  
Research Institute of Uranium Mining  
Hengyang Hunan Province, China

A personal alpha dosimeter for measuring exposure to radon and thoron daughters has been developed and tested in China since 1981. The dosimeter consists of a pump and a detector head. The former, weighing 400 gms is worn by each miner through the entire shift; and the latter, enclosing three ultra-thin  $\text{CaSO}_4 \cdot \text{Tm}$  thermoluminescent chips and a synthetic fibre filter, is mounted on the underside of the hard hat brim. These two parts are connected by a rubber hose extending from the back of the hat to the belt. Detecting is by two of the thermoluminescent chips positioned directly in front of the filter through which sample air is drawn continuously at a constant flow rate. An identical third chip is used for correcting external gamma radiation. Response is linear over six decades of cumulative working level exposure and the lower detection limit is  $1.04 \text{ J} \cdot \text{hm}^{-3} \text{h}$  ( $3.10^{-4} \text{ WLM}$ ). The prototype units have been subjected to a series of laboratory and field tests. A calibration of TLD net response versus exposure was obtained in the first underground test in a uranium mine. The correlation is  $104.8 \pm 3.6$  net reader counts/WLH, with 95% confidence limits. A set of five dosimeters was tested to determine the precision of the instrument in measuring working level hours of exposure. The results obtained show a standard deviation of  $\pm 20$  percent in measuring 0.5 to 138 WLH exposure.

LOCAL STATIC METHOD FOR MEASURING RADON  
EMANATION RATE FROM POROUS MATERIALS

BY: Zhang Zhe  
Uranium Mining Institute of the  
Ministry of Nuclear Industry  
Hunan Province, China

The local static method (LSM) applied to measure radon emanation rate (RER) is also called accumulation method. If LSM is used to measure RER from porous materials, the reverse diffusion and leakage of radon must be considered. Otherwise, the value of RER would be small.

Considering such state, the raising of radon concentration in collecting hood should be described by

$$C(t) = \frac{\dot{s}}{eV} [1 - \exp(-e t)] + C_0 \exp(-e t)$$

where:  $C(t)$  = radon concentration in collecting hood at time  $t$ .  
 $\dot{s}$  = RER from porous materials.  
 $s$  = radon emanation area.  
 $V$  = Volume of collecting hood.  
 $e$  = effective decay constant.  
 $t$  = collecting time.  
 $C_0$  = radon concentration in collecting hood at  $t=0$ .

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Because the  $\lambda$  is unknown this formula could not be used to measure RER directly. But when the sampling interval is kept constant in the period of measurements, the relation between  $n$ th and  $n-1$ th samples is expressed as follows:

$$C_n = \frac{\delta s}{\lambda eV} [1 - \exp(-\lambda t_0)] + C_{n-1} \exp(-\lambda t_0)$$

where:  $t_0$  = sampling interval.

$$\text{make } A = \frac{\delta s}{\lambda eV} [1 - \exp(-\lambda t_0)]$$

$$B = \exp(-\lambda t_0)$$

Clearly A and B are constants, then

$$C_n = A + B C_{n-1}$$

$$\text{and } = A V \ln B / t_0 (B - 1)$$

As the numbers of sample  $n=3$ , A and B can be obtained by solving a linear simultaneous equations. While, for  $n=4$ , A and B can be obtained by means of least-square method for reducing the errors.

Experimental results indicate that the above analysis is well in keeping with practice. If the RER from rock surface is measured, the relation may be simplified and the results are the same as that with other formulas.

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#### DOSIMETRY

#### A REVIEW OF ALL SOURCES OF EXPOSURE TO NATURAL RADIATION IN UK MINES

BY: D.W. Dixon, A.C. James, J.C. Strong and A.D. Wrixon  
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Oxon OX11 0RQ, UK

Radon decay products are the major cause of human exposure in UK mines. Little attention has therefore been paid to the contributions from the other sources: thoron decay products, long-lived radionuclides in mine dust, and gamma-rays. It is, however, necessary to quantify them so that comparisons can be made with the ICRP limits, which apply to the total of all doses.

Comprehensive surveys of radiation levels have been made in eleven mines - two tin, two ballclay, one slate, one gypsum, one potash, one fluorspar and three coal mines. Exposures to radon decay products were computed from spot measurements of radon and radon decay product concentrations made throughout each mine and from measurements of the integrated radon concentrations at selected positions over several months. Exposures to thoron decay products were obtained by measurement of the alpha activity on filters used to sample mine air following the complete decay of the radon decay products. Exposures to mine dust and gamma-rays were calculated from measurements of the specific activity of rock samples.

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This paper will contain the results of these assessments. Comparisons will also be made between the radon and thoron decay product concentrations in upcast air and the underground concentrations with a view to investigating the value of upcast air measurements as a means of screening mines for the exposure of miners.

#### BIOLOGICALLY SIGNIFICANT PROPERTIES OF REFINED URANIUM ORE

BY: A.F. Eidson, E.G. Damon  
Lovelace Inhalation Toxicology Research Institute  
Albuquerque, New Mexico, U.S.A.

Dose estimates and hazard evaluations for uranium milling effluents have a firmer basis when they include a description of the properties of uranium products and of their behavior in laboratory animals. In a study of this type, uranium aerosols were sampled during normal operations at four mills. Median aerosol concentrations in packaging areas ranged from 0.04  $\mu\text{g U/l}$  to 0.34  $\mu\text{g U/l}$ . The aerosols were heterogeneous, and 14% to 76% (by weight) of the airborne uranium was in particles with aerodynamic diameters greater than 12  $\mu\text{m}$ . Appreciable amounts of airborne uranium would be expected to deposit in the nasopharyngeal compartment of the respiratory tract if inhaled by a worker not wearing respiratory protection. In vitro solubility of yellowcake was compared with in vivo retention of yellowcake aerosols. Infrared analysis showed that yellowcake contains relatively soluble ammonium diuranate and less soluble  $\text{U}_3\text{O}_8$ . In vitro studies indicated that 85% of Mill A yellowcake had a dissolution half-time ( $T_{1/2}$ ) of 1 day, and the remainder had a  $T_{1/2}$  of 500 days. For the Mill D sample, 25% had a  $T_{1/2}$  of <1 day, and 75% had  $T_{1/2}$  of 300 days. Rats were exposed by nose-only inhalation of either Mill A or Mill D yellowcake. For the Mill A yellowcake, 78% of the lung burden cleared with  $T_{1/2}$  of 0.5 days, and 22% with  $T_{1/2}$  of 240 days. For the Mill D yellowcake, 25% of the initial lung burden cleared with  $T_{1/2}$  of 3.5 days, and 75% with  $T_{1/2}$  of 110 days. The results indicate that ammonium diuranate and  $\text{U}_3\text{O}_8$  behave in lung as Class D and Y compounds, respectively. (Research supported by the U.S. Nuclear Regulatory Commission via U.S. Department of Energy Contract No. DE-AC04-76EVO1013 under an interagency agreement between the Nuclear Regulatory Commission and the U.S. Department of Energy.)

#### DIFFERENCES IN IN VITRO DISSOLUTION PROPERTIES OF SETTLED AND AIRBORNE URANIUM MATERIAL\*

BY: R.C. Scripsick, M.I. Tillery, S.C. Soderholm  
Los Alamos National Laboratory  
AND BY: K.C. Crist, Conoco Inc.

The hazard associated with inhalation of uranium compounds depends on the in vivo solubility rate of material deposited in lung. In vitro methods have been shown to be useful in predicting these in vivo rates. Two environmental uranium materials were analyzed using in vitro dissolution techniques, one was settled dust and the other airborne dust. Both materials were produced during test firing of depleted uranium penetrator munitions. Certain differences in the in vitro dissolution properties of the respirable fraction of these materials were found.

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Results of this study suggest that differences in the dissolution properties of settled and airborne uranium materials exist; the airborne material has shorter long-term dissolution half-time and a larger fraction dissolving in the initial (rapid) dissolution phase. These differences may affect estimation of the hazard associated with exposure to airborne uranium based on in vitro solubility measurement of settled dust. The dissolution differences may be the result of chemical and physical differences in the materials studied. Such differences could also exist in uranium materials found at uranium mines and mills.

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\*Work performed at the Los Alamos National Laboratory under the auspices of the U.S. Department of Energy, Contract No. W-7405-ENG-36 and supported by the U.S. Air Force, Eglin Air Force Base, Air Force Armament Laboratory (Environics Office).

COMPARISON OF URANIUM RETENTION IN DOGS EXPOSED  
BY INHALATION TO TWO YELLOWCAKE FORMS

BY: E.G. Damon, A.F. Eidson  
Lovelace Inhalation Toxicology Research Institute  
Albuquerque, New Mexico, U.S.A.

Two groups of 20 Beagle dogs each were exposed to aerosols generated from dry yellowcake powders obtained from either of two uranium mills. The two materials represented extremes in yellowcake composition that occur in industry. Based on infrared analysis, one sample was 100% ammonium diuranate (ADU), and the other was 99%  $U_3O_8$ . Aerosol particle size distributions measured using seven-stage cascade impactors were: (1) mass median aerodynamic diameter (MMAD) =  $3.4 \pm 0.5 \mu m$  (mean + S.E.M.) with geometric standard deviation (GSD) of  $1.5 \pm 0.04$  for the 100% ADU sample, and (2) MMAD =  $3.0 \pm 0.3 \mu m$  with GSD of  $1.7 \pm 0.1$  for the 99%  $U_3O_8$  sample. Initial lung burden of each dog was estimated during exposure, using the average aerosol concentration monitored by a Model RAM-S nephelometer, the exposure duration, respiratory minute volumes of dogs measured during exposure using a whole-body plethysmograph, and an assumed deposition efficiency of 20% for the pulmonary compartment. The average estimated initial lung burden for dogs exposed to 100% ADU was  $130 \pm 9 \mu g U/kg$  body weight, and for those exposed to 99%  $U_3O_8$  it was  $140 \pm 7 \mu g U/kg$  body weight. Dogs were sacrificed at intervals during 2 years after exposure. Tissues were fluorometrically assayed for uranium content. Early results from whole-body retention data indicate that ADU and  $U_3O_8$  behave in dog lung as Class D and Y compounds, respectively. (Research supported by the U.S. Regulatory Commission via U.S. Department of Energy Contract No. DE-AC04-76EVO1013 under an interagency agreement between the Nuclear Regulatory Commission and the U.S. Department of Energy.)

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URANIUM MEASUREMENTS IN URINE: A SUMMARY OF THE  
OPERATING EXPERIENCE AT CANADIAN URANIUM MILLS

BY: W.A. Napier, B.C. Smart  
Atomic Energy Control Board  
Ottawa, Ontario, Canada

Current methods of producing yellowcake at Canadian Uranium Mills are reviewed, and the uranium products classified in terms of their potential solubility in lung fluid. The purpose of the uranium in urine programs is discussed along with the methods used for sampling and analysis at the mills. Interlaboratory comparisons have shown that the data, obtained over the past 3-4 years, are of sufficient accuracy to warrant further examination. The data collected for 1982 and 1983 are reviewed. Trends are identified for various worker classifications. Workers at risk are identified and recommendations made with respect to the sampling strategy employed at the mills.

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INSTRUMENTATION/VENTILATION/ENGINEERING

COMPARING PERSONAL ALPHA DOSIMETRY WITH THE CONVENTIONAL AREA  
MONITORING-TIME WEIGHTING METHODS OF EXPOSURE ESTIMATION:

BY: A.B. Balint and J. Viljoen  
Atomic Energy Control Board  
Ottawa, Ontario, Canada

The development and implementation of a personal alpha dosimetry program for monitoring exposures of uranium mining facility workers in Canada is presented in this paper. All facilities participate in the program and consequently there is good representative data available for assessment.

Area monitoring-time weighting methods used and results obtained to determine individual radon and thoron daughter exposure and exposure results generated by using dosimeters are assessed and compared.

Dosimetry techniques, description of dosimeters being used by licensees, performance and problems associated with the implementation of the programme as well as technical advantages and difficulties experienced are discussed.

An interesting comparison between the Canadian and French experiences are made and finally a concluding statement summarizes the evaluation of the programme and identifies the regulatory position.

RADON CONCENTRATIONS IN AIR OF POLISH UNDERGROUND COAL MINES

BY: W. Chruścielewski, A. Żorawski  
J. Olszewski, T. Domanski  
Institute of Occupational Medicine, Poland

In all underground Polish coal mines the survey of radon concentrations was done during 1980 and 1981 under the Research Programme of Occupational Carcinogenesis /within the frame of the Governmental Programme-PR 6/. The system of concentration measurement, so-called Environment Cassette System /ECS/ was based

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on the use of special passive cassettes with the detector material type LR - 115. The cassettes was placed in every one of the mines, in the typical work-places, transportation roads and cross-adits. The time of exposure was 1 month. Altogether 827 measurements were performed in the 67 underground mines.

The mean radon concentration calculated for all the measurements done is 20 pCi/liter with variability range from 0 up to 400 pCi/liter, occasionally. The paper presents the distribution of observed concentrations in each mine. The paper also contains the authorized levels and limits presently used in Poland.

#### EXPERIMENTAL VERIFICATION OF THE THEORY OF CLUSTERS

BY: M.J. Hawrynski  
Institute of Occupational Medicine  
P.O.Box 199, 90-950 Lodz, Poland

Experimental verification of the theory of clusters is described in this paper. The measurements of diffusion coefficient of charged RnDP fraction in various relative humidities of air were done. Dynamic theory of clusters has been proved, whereas the static theory has not.

#### IDENTIFICATION OF NON-URANIUM MINES WHICH PRESENT A RADON RISK THROUGH MEASUREMENTS OF THE EXHAUST AIR

BY: (1) S. Bernhard, J. LeGac, P. Zettwoog (2) H. Seguin  
(1) Commissariat a l'Energie Atomique, Fontenay-aux-Roses, France  
(2) Commission des Communautés Européennes, Luxembourg

In an earlier campaign carried out in 8 non-uranium mines within the European Community, individual radiation exposures were measured. It became apparent that some of these mines were to fall under a new European directive of July 15, 1980, related to health protection against the risk from ionizing radiation.

The EC authorities wished to know precisely what the consequences would be of applying this directive to non-uranium mines.

For this purpose, we have sought to develop a simple and uncostly method of identifying the mines in which the levels of exposure to radon daughters could be significant, in the context of the EC directives.

It has been demonstrated that the measurement of a certain number of parameters in the general exhaust air of a mine, combined with knowledge of the geometric characteristics of the tunnels and stopes, make it possible to calculate the value of 4 significant criteria. Exceeding the corresponding threshold for any one of these 4 criteria indicates a strong presumption that a significant level of risk exists.

The model which supports this approach is described as well as the experimental results obtained on a new sample of non-uranium mines.



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RADON TRANSPORT INTO UNDERGROUND OPENINGS

BY: Robert F. Holub  
U.S.A.

Bureau of Mines of the U.S. Department of Interior completed a study on radon transport. A steady state equation including both diffusion and forced flow satisfactorily describes the process of transport through and in porous media. If the equation is used in laboratory experiments, permeability, diffusion coefficient, porosity and tortuosity for a core sample can be obtained. For large underground openings (mines) a two phase description can be used. It consists of a radon and an air component that - in the first approximation - move independently of each other. If the total volume of the opening, ventilation rate, average ore grade and the emanation coefficients are known, radon concentrations in the opening can be calculated at least within an order of magnitude. These results are useful for radon control and mine design.

RADIATION MONITORING PROGRAM IN ITALIAN NON-URANIUM MINES

BY: G. Sciocchetti, F. Scacco, P.G. Baldassini, R. Sarao  
ENEA Environmental Measurements Laboratory  
Roma, Italy

Radiation protection in underground non-uranium mines presents peculiar aspects as a consequence of the complexity of radon sources and the variable concentration levels.

The Italian act on the radiological protection and the relevant regulatory control procedures are implemented on a stepwise application based on the following principles:

- preliminary assessment of the geomorphological and radiological characteristics of the mine performed by governmental authorities and agencies;
- radiation monitoring carried out by the mine licensee, if needed;
- application of remedial actions and/or routine control of miners exposure, if needed.

A national pilot survey of the radiological characteristics of about 50 underground non-uranium mines has been carried out by the governmental agency ENEA with the cooperation of the Department of Industry. The results of measurements evidenced that in some non-uranium mines and in particular conditions (i.e. inefficient ventilation) radon and daughter concentrations may grow up to significant levels. These studies have put in the right perspective the radiation hazards linked to the occupational exposure in underground non-uranium mining. An "optimized" national monitoring program has been designed to meet the following objectives:

- to test periodically, at low cost and manpower, a large number of non-uranium mines characterized by variable radon levels;
- to carry out sampling, measurements and relevant exposure assessment by means of a central laboratory;
- to advise competent authorities to plan control procedures and, if needed, to test the effectiveness of remedial actions.

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The radiological characteristics of each mine were outlined on the basis of a control scheme that included the monitoring of various working areas and radon flux rate in the upcast air of the surveyed mines. Long-term measurements of radon concentration were carried out using the passive ambient ENEA dosimeter. The radon daughter exposure was estimated using the disequilibrium F-factor for radon and daughter concentration experimentally determined. A monitoring station equipped with active measuring instrumentation developed by the ENEA laboratory was put in operation in experimental mines to determine the most typical values of the equilibrium factor and to test the correlation between the "continuous" measurements of radon concentration and the integrated response of passive dosimeters in various environmental conditions. Active and passive measuring devices were previously calibrated in the ENEA radon chamber simulating mining conditions. The monitoring systems, the passive dosimeter and a new "patent pending" portable operational potential alpha energy meter, are described. Results are reported concerning the screening measurements inside Italian non-uranium mines on country scale. Statistical aspects of the adopted control scheme, checked also against personal monitoring data, and the feasibility of the "optimized" monitoring program based on passive area monitoring are experimentally tested and discussed. It is experienced that appropriate countermeasures based on passive area monitoring screening data, mainly the implementation of the ventilation system, could meet the radioprotection objectives in non-uranium underground mining.

Tuesday, October 16, 1984 - Session 6b 14:00-17:00  
EPIDEMIOLOGY

INHERENT DOSIMETRIC AND EPIDEMIOLOGICAL UNCERTAINTIES ASSOCIATED  
WITH LUNG CANCER RISK ASSESSMENT FOR MINING POPULATIONS

BY: F. Steinhausler, W. Hofmann  
Division of Biophysics  
Salzburg, Austria

Decisions on occupational dose limitations for miners require the quantification of the lung cancer risk due to inhaled radon daughters, together with its uncertainties. For this purpose several data groups ranging from individual exposure data to radiobiologically-based assumptions about the risk concept are used as input data in a complex algorithm. The present risk assessment by ICRP uses the dosimetric and epidemiological approach. Both procedures are associated with significant problems either due to methodological uncertainties, or insufficient demoscopical and physiological data and information on past exposure history.

In the presentation the uncertainties of the following parameters are investigated with respect to their overall contribution to the numeric risk assessment:

- 1) Occupational and non-occupational cumulative exposure to short- and long-lived radon daughters, external gamma radiation and uranium ore dust.
- 2) Lung cancer diagnostics as a result of either pathological, histological or cytological methods used.
- 3) Conceptual differences in dosimetric modelling with regard to model assumptions.
- 4) Inter- and intra-subject variabilities of anatomical parameters.

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- 5) Influence of non-radiological cofactors (smoking, air pollution).
- 6) Dose-time-response relationship and risk-concept (linear/ non/linear extrapolation and single/multiple interacting factors).

The resulting total uncertainty due to the combination of all uncertainties associated with the above parameters is calculated for the absolute and relative risk concept by using statistical methods of error propagation. The results indicate that from the available data the probable value for the risk factor of radon daughter-induced lung cancer lies within a bandwidth of values differing by more than an order of magnitude.

#### THE ONTARIO MINERS MORTALITY STUDY 1955-1977 PROGRESS REPORT

BY: J. Muller, W. Wheeler,  
J. Gentleman, G. Suranyi,  
R. Kusiak

A general outline of the study and a description of materials and methods used was given in an earlier report.(1)

The study group consisted of 50,201 men who were observed for 754,391 person-years between 1955 and 1977. There were 6757 deaths observed in the study population as compared to 6804.6 deaths expected on the basis of age and calendar-specific Ontario male population data. For many causes of death, there were fewer deaths observed than expected and this was most likely due to the "health worker effect".

A total of 1253 violent deaths was observed during the study period as compared to 679.6 expected. Death rates from non-neoplastic lung disease, mainly due to silicosis and silico-tuberculosis, were greatly increased in underground gold and uranium miners as well as in men who have mined a variety of ores. No such increase was, however, observed in nickel-copper, iron ore, or other ore miners.

Similarly a significantly increased risk of cancer of the trachea, bronchus and lung was observed in underground gold and uranium miners, as well as in men who mined a variety of ores. No such increase in risk was detected in nickel-copper, iron ore and other ore miners.

In uranium miners 119 deaths from cancer of the trachea, bronchus and lung were observed up to the end of 1977 as compared to 65.78 deaths expected and a preliminary risk factor for exposure to the short-lived daughters of Radon - 222 is given.

At present the death search for uranium miners is being updated to the end of 1981 and correction for various confounding factors will be carried out in the new risk estimate for radon daughters. The association of lung cancer risk with exposure to various environmental factors in the gold mines is being investigated.

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- (1) The Ontario Miners Mortality Study, General Outline and Progress Report. J. Muller, W. Wheeler, J. Gentleman, G. Suranyi, R. Kusiak, M. Smith, 1981.

Radiation Hazards in Mining, Golden, Colorado. Manuel Gomez (ed.) Published by the Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers Inc., New York, N.Y., pp. 359-362.

January 17, 1984

ACTUAL STATE OF THE EPIDEMIOLOGICAL STUDY OF URANIUM MINERS IN FRANCE

BY: M. Tirmarche\*, J. Brenot\*, J. Piechowski\*, J. Chameaud\*\*, J. Pradel\*

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A close cooperation of the medical staff in the mines (COGEMA) and of the Departments of Health and Technical Protection of the IPSN (CEA) has made it possible to start an epidemiological study of the French uranium miners. The aim of this work is to study any excess mortality by cancer of this cohort of miners, mainly mortality by bronchogenic lung cancer, and to establish a relation between this excess mortality and the exposure to radon daughters.

The population of miners concerned by this study has now been defined. We intend to register firstly all the miners having worked underground for more than three months and secondly all the others, since operation of the first mine (1947) up to 1980.

As a first step, our efforts will chiefly concern those miners having worked during the first twenty years, when the exposure to radon daughters was higher than today. An estimation of the monthly exposure levels to radon in the different mines between 1947 and 1956 gives a range of values between 1 and 10 WLM (Working Level Month). Since 1956, a systematic monitoring of the concentration of radon or of radon daughters in the mines gives reliable dosimetric records for each miner.

The search of the causes of death presents some difficulties in France. Being anonymous, the national registry of death causes does not allow the identification of a given individual. If a miner dies during his working life, the cause of this death is known by the medical staff of the mines in most of the cases. If a miner dies when retired, we have to ask his family, the family's physician, the local hospital...

This paper gives the progress of the different steps of this study, with a detailed description of a first group of miners having worked underground in the 1947-1972 period.

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LUNG CANCER INDUCTION IN RATS BY RADON DAUGHTER EXPOSURE  
STATUS AS OF 1984 ON LOW DOSES EFFECTS

BY: J. Chameaud, R. Masse, J. Lafuma

We have previously established a dose effect relationship for lung cancer induction in the rat by high radon daughter exposure. The risk coefficients for cancer induction derived from these studies were found comparable to dose derived from miners follow up.

Here we review the results of a 2400 rat study where cumulative exposure were kept below 100 WLM. The dosimetry was performed with an active track dosimeter, measuring total potential energy in a subgroup of 600 controls and 1000 exposed rats.

Determination of equilibrium factors for different conditions of exposure allowed to reassess the dosimetry in a former 800 rat subgroup.

Actual results indicate a linear no threshold relationship for lung cancer induction between 0 and 100 WLM with a doubling dose equal to 20 WLM.

The tumors were induced by exposure without cofactor association like tobacco smoke or diesel exhausts.

The results are discussed as well as the consequences for the protection of uranium miners.

MORTALITY EXPERIENCE AMONG WORKERS IN THE URANIUM INDUSTRY

BY: R.C. Nair, J.D. Abbatt  
G.R. Howe, H.B. Newcombe

A retrospective cohort study involving some 19,000 employees of Eldorado Nuclear Ltd. was conducted and the preliminary results from that study are reported here. The workers have been employed in the mining of uranium ore, refining of radium and uranium, as well as in the support services, since the 1930's. The mortality experience of these workers between 1950 and 1980 was obtained from Statistics Canada mortality records, using computerized record linkage. The exposure levels and work history data were compiled from company records.

The Standardized Mortality Ratios and the Proportionate Mortality ratios were calculated for the various causes of death, using the Canadian population as the standard and adjusting for age as well as calendar year of death. These were compared for various exposure levels, measured as working level months (WLM), for various occupational groups and between work sites.

An overall two fold excess of lung cancer deaths and deaths due to external causes were noted in the male cohort. However this excess seems limited to the two mining operations, with the refinery group showing a healthy work effect. Risk factors are estimated and compared with the results of previous studies.

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LUNG CANCER MORTALITY AND RADIATION EXPOSURE  
AMONG THE NEWFOUNDLAND FLUORSPAR MINERS

BY: H.I. Morrison\*, R.M. Semenciw\*, Y. Mao\*, D.A. Corkill\*\*,  
A.B. Dory\*\*, A.J. deVillier\*, H. Stocker\*\*, D.T. Wigle\*

\* Health and Welfare Canada

\*\* Atomic Energy Control Board

The mortality experience of approximately 2000 fluorspar miners in St. Lawrence, Newfoundland will be received for the period 1933-1982 in relation to their exposure to radiation due to radon daughter products. New estimates of radiation exposures from radon daughters will be presented, based on more complete work histories and refined estimates of historic radiation levels in the mines. As found in previous reports, lung cancer accounted for most of the excess deaths among exposed workers.

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POSTER SESSION

PHYSICAL AND ENVIRONMENTAL SURVEILLANCE IN  
URANIUM EXPLORATION GALLERIES

BY: A. Bassignani, D. Ippolito  
AGIP, MILAN, ITALY

The work describes the criteria and the formalities established for the organization of the radioprotection in the uranium exploration areas in Italy and for the evaluation of the potential radiological impact on the mine's environment. As well known, the main radiological risk is determined by inhalation of radon and radon daughter in addition to external gamma exposition, thus, since the 1977, it has been introduced a radioprotection standard which takes into account the doses to lung and skeleton deriving from the inhalation of radon daughter and the dose to total body.

In the work are reported the integral values of the exposure levels collected during 5 years by measuring representative samples of the inhaled air and by means of measures of external exposure made by thermoluminescent dosimeters (CaSO<sub>4</sub> Dy). Particular care has been taken to the characterization of the environmental radiometric conditions in order to determine the possible impact of the mining activities. The work also reports the relevant levels of natural radioactivity existing in the site surrounding the uranium exploration, pointing out the seasonal and annual variations of the natural radioactivity by itself. The whole of the data concerning the controls, indicates that for what concerns the exposition of persons into the galleries, it is never been exceeded the half of the integral value reported by the Standard. However, such a result has been obtained thanks to the application of measures such the increase of ventilation rates, tubing of the mine's waters and subdivision of the galleries into areas. On the contrary, as regards the surrounding site, the two cycles of measurements carried out, have not pointed out relevant changes of the levels of environmental radio-activity, levels that are essentially due to radiometric anomalies coming from ore outcrops. In fact, the facilities applied to contain and to compact the tailings, have obtained among the other results, that the radioactive levels on the dumps as well shown by the reported data, do not increase from those of the surrounding environment.

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DERIVED SURFACE CONTAMINATION LIMITS FOR  
THE URANIUM MINING AND MILLING INDUSTRY

BY: S.H. Ching  
Canada

A derived surface contamination limit has been established for the uranium mining and milling industry using ICRP30 recommendations and the assumption of secular equilibrium among different radionuclides in the uranium chains.

This derived surface contamination limit is then used as a guide to establish a surface contamination limit for the release of slightly contaminated materials for re-use outside the nuclear industry.

THERMOPHORETIC COLLECTION OF RADON DAUGHTERS WITH  
POTENTIAL APPLICATION TO PERSONAL DOSIMETRY

BY: H. Leung and C.R. Phillips  
Department of Chemical Engineering and Applied Chemistry  
University of Toronto, Toronto, Ontario

The mechanism of thermophoresis for possible application to the collection of radon daughters in a personal dosimeter was examined under the condition of constant temperature gradient across two parallel discs. The thermophoretically collected radon daughter activities were found to be linear with temperature gradient at a constant Working Level, and with Working Level at a constant temperature gradient, thereby resulting in a constant conversion factor for the dosimeter ( $\text{dpm}(\text{°C}/\text{cm})\text{WL}$ ). Values of thermal velocity per unit temperature gradient agreed with theoretical predictions for thermophoretically transported aerosols. However, in order to provide a protective barrier against wind velocity effects in a personal dosimeter, a temperature gradient of several times that required for thermophoretic collection, of the order of several thousand  $\text{V}/\text{cm}$ , may be needed.

NEW CAPABILITIES FOR MEASUREMENT OF NATURAL RADIOACTIVITY  
USING HIGH PURITY N-TYPE GERMANIUM DETECTORS

BY: S.D. Schery, Physics Dept.  
New Mexico Institute of Mining and Technology  
Socorro, New Mexico

The new generation of co-axial N-type germanium detectors is characterized by improved sensitivity to low-energy photons and increased surface area. These features permit new applications involving direct photon spectrometry not possible with standard co-axial detectors. Previous work has demonstrated the suitability of these detectors for direct assay of Pb-210 in environmental

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samples.\* Currently our laboratory can assay concentrations as low as 0.1pCi/gm (+ 15%) without chemical processing. Present research focuses on applications using even lower energy photons. For example, under certain conditions it may be possible to assay directly U-234 or U-238 in environmental samples using their L X-rays (<20 keV). The problems of interferences, attenuation in the vacuum can, and background contamination in the materials of the detector assembly will be mentioned. Detector design considerations and cost effectiveness will be discussed.

\* S.D. Schery, "Determination of Pb-210 in Environmental Samples by Gamma Spectrometry with High Purity Germanium Detectors," Anal. Chem. 52, 1957 (1980).

#### APPLICATIONS OF PASSIVE RADON DOSIMETERS IN MINING AREAS

BY: M. Urban, J. Schmitz  
Karlsruhe Nuclear Research Centre  
Federal Republic of Germany

The knowledge of the individual exposure to radon and its daughter products is essential for effective radiation protection of miners. Therefore they should be supplied with personal dosimeters not only for external radiation but also for radon and its decay products. Besides the personal dose commitment there is also a potential impact on the environment by radon through mine dumps, uranium mill tailing ponds and mine ventilation.

Two different types of passive radon dosimeters developed at Karlsruhe Nuclear Research Center have been applied for their use as monitors in mines and mining areas. The passive radon diffusion chamber used in the national survey in German houses and outside air has been used as a working place monitor in mines and as an environmental monitor. The new personal passive radon dosimeter has been tested under mining conditions.

The results of the applications in mining have been compared with measurements using the MDA-IWLM 811 and the CEA personal radon dosimeter. They were also correlated to typical underground works in an uranium exploration mine.

The radon concentration in the environment of several mines has been determined for a longer period and they were correlated to mining activities and meteorological parameters.



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THE PYLON 190: A NOVEL FILTER CALIBRATION STANDARD  
FOR ALPHA SPECTROMETRY

BY: G. Vandrish, K. Theriault, F. Ryan  
Pylon Electron Development Co. Ltd.  
Ottawa, Canada

The deposition behaviour of radon and thoron progeny within the 190 standard was studied and the suitability of the system for the calibration of alpha spectrometers and working level measurement instrumentation is discussed.

The information is now ready for data processing. Analysis will focus on the role of paternal occupational exposure to uranium mining, and paternal and/or maternal exposure to uranium mine tailings in the aetiology of these birth anomalies.

THE TRANSIENT RESPONSE OF RADON AND THORON CHAMBERS

BY: S. Pogorski and C.R. Phillips  
Department of Chemical Engineering and Applied Chemistry  
University of Toronto, Toronto, Ontario

A transient model was developed to evaluate the time-dependent concentration response of a radon/thoron chamber. Such a model has important applications when the atmosphere in the chamber is initially set up or varied for the purpose of calibrating or testing instruments or dosimeters. The radon daughter concentration was found to increase with residence time as well as with aerosol concentration, the latter a consequence of attachment of daughters to aerosols. The spatial concentration distribution in the chamber was measured and, although the variance was larger than can be explained by the inherent variance of the measurement technique, it was not large enough to warrant the inclusion of spatial parameters in the model. The assumption that wall plate-out is constant with time was found to be valid. The effect of removal of radon daughters by grab sampling was modelled so as to allow prediction of the new steady state which results following the taking of a number of samples.

RESEARCH AND DEVELOPMENT OF EQUIPMENTS OF RADON DAUGHTERS  
IN UNDERGROUND MINES

BY: M. Pourprix, J. Vendel  
IPSN/DPT/SPIN  
Commissariat à l'Energie Atomique  
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During the profession of mining works in an underground mine, the ventilation in operation may become inadequate to ensure the working sanitation. This may result from the increasing strength of the works, the progressive contamination

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of the primary air by old works, and the occurrence of radon-strongly emitting rocks. We thought that the problems raised could be solved at a low cost at least momentarily by putting, on the auxiliary ventilation, radon daughter cleaners, also effective for ore dusts.

The progress of the research and development programs on various types of apparatus is described: some equipments are operating as prototypes in underground mines.

The possibility and advantages of the cleaning of primary air or individual working spaces are examined.

#### ACTIVATED CHARCOAL USED FOR RADON ABSORPTION WITH BULKHEADS

BY: C.T. Sheeran, J.C. Franklin  
U.S.A.

Laboratory tests were run to determine the effectiveness of activated charcoal in absorbing radon from air being exhausted from areas sealed with bulkheads. The relative humidity was varied from 20 to 100 percent to determine the change in radon absorption with changing humidity.

The charcoal tested was +20 to +200 mesh which was made from coconuts. Radon concentrations of approximately 2,000 pci/l were pulled through traps ranging from 3.8 to 20.3 cm in diameter and up to 122 cm in length at a flow rate of 1.6 liters per minute. At these flow rates and concentrations the charcoal absorbed approximately 97 percent of the radon for longer than 150 days with a relative humidity of 20 - 25 percent.

#### RADON AND RADON DAUGHTER PRODUCTS: THEIR CHEMISTRY AFTER ALPHA-DECAY

BY: D. Thibodeau, D.R. Wiles  
Chemistry Department, Carleton University  
Ottawa, Canada

Radon-222, radon-220 are the gaseous decay products in the decay chains of uranium-238 and thorium-232 respectively. These radioactive gases constitute a hazardous source of radiation for uranium mine workers, through direct inhalation of radon or of its daughter products. These atoms are known to absorb on nearby surfaces (dust particles, walls, and so on) but the chemistry of this absorption is not known. Our studies of the absorption of radon-220 daughters on metal and other surfaces reveal a selectivity in the absorption which we anticipate may prove to be important both for the trapping of the airborne radioatoms (for air monitoring and for air cleaning) and for the prevention of their deposition (on walls, equipment and other surfaces). The results to date indicate that the absorption follows an exponential decrease as a function of distance from the source of radon. This function is being used to observe differences in the absorption affinity of various absorbent materials.

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MEASUREMENTS OF RADON AND DECAY PRODUCTS IN NON URANIUM  
MINES OF THE FEDERAL REPUBLIC OF GERMANY USING ACTIVE AND  
PASSIVE METHODS

BY: R. Kompa, J. Pensko, H. Schmier  
Institute for Radiation Hygiene  
Federal Health Office of the  
Federal Republic of Germany

A survey on the radiation exposure by radon and its short-lived decay products in different non-uranium mines of the Federal Republic of Germany has been conducted. The ventilation of these mines ranges from natural and artificial ventilation to continuous ventilation during 24 hours with an air output of about 20 000 m<sup>3</sup> min. The number of underground workers varies between a few persons and several hundreds of miners.

The variation of the values obtained in continuous measurements of the decay product concentration within the mines is well correlated with the influence of ventilation. The little variation of the  $\alpha$ -dose rate observed in a few mines shows a similar correlation. The calculated equilibrium factors range from 0.3 to 0.8. In two out of 15 mines under study the exposure limit of 5 WLM/a for uranium miners recommended in ICRP (1981) is exceeded. In both cases simple measure would suffice to reduce the radon daughter product concentration.

MONITORING OF RADIATION EXPOSURE FROM DIFFERENT NATURAL  
SOURCES IN POLISH COAL MINES

BY: J. Lebecka, I. Tomza, K. Skubacz,  
S. Chalupnik, J. Skowronek  
Central Mining Institute, Katowice, Poland

The main subject of research work in Polish coal mines are the instrumentation and results of measurements of radon-daughters, radium-bearing waters and radioactive deposits. An integrating WL-monitor with TLD-chips designed as a supplement to the commercial dust sampler has been developed. A method of calibration of WL-monitors by means of liquid scintillation counting has been described. Radon-daughters concentration in mine workings did not exceed 13  $\mu$ l/m. The deposits precipitated from radium-bearing waters contained up to 170 kBq/kg of radium isotopes. In most of the investigated workplaces the radiation exposure does not exceed the limit recommended by ICRP for occupational exposure.

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Wednesday, October 17, 1984 - Session 8a 09:30-12:00  
VENTILATION/ENGINEERING

NON-STEADY STATE RADIATION MINE MODELS - PRACTICAL APPLICATIONS  
TO PERSONAL DOSIMETRY AND ENVIRONMENTAL MONITORING

BY: J. Bigu  
Energy, Mines and Resources Canada

Theoretical mine models are useful for predicting airborne radon and radon daughter levels. A simplifying assumption frequently made in these models is that steady-state conditions prevail. However, it is a well documented fact that field conditions are, in general, far from constant. A mine model has been developed that incorporates a time-dependent source term (i.e. exhalation rate) and ventilation rate. The model is equally applicable to radon and thoron, and their daughter products, and, hence, ideally suitable for underground uranium mines where thoron gas is present. The model permits calculation of decay products disequilibrium ratios, age of air, ratio of radon and thoron Working Level, and other relevant radiation variables. In addition, removal of airborne decay products by plate-out to mine walls, based on field data, is taken into account. The mine model is particularly helpful for studying the response of time integrating radiation devices (e.g., personal dosimeters and environmental monitors) in time-dependent radiation atmospheres, a problem of considerable practical interest for personal dose estimation purposes. Theoretical predictions are made using linear, exponential, sinusoidal and step-function time source-dependent terms. Generalized analytical expressions are presented leading from the calculation of radiation levels to the behaviour predicted for radiation instrumentation under varying radiation conditions. Theoretical and experimental data are discussed.

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COMPUTER MODELING OF RADON TRANSPORT INTO  
UNDERGROUND OPENING

BY: (1) Robert C. Bates and (2) Robert F. Holub

- (1) Supervisory mining engineer, Spokane Research Center, U.S. Bureau of Mines, Spokane, WA.
- (2) Research physicist, Denver Research Center, U.S. Bureau of Mines, Denver, CO.

A number of approaches have been proposed for quantifying radon flux by diffusion and forced flow. Many of these expressions are described, and the results of their use to estimate radon flow into mine openings are compared to show their benefits and limitations. Considered here are methods that assume either diffusion or forced flow predominates to those steady-state and computer-based, time-dependent models that permit simultaneous evaluation of both transport mechanisms. Finally, some comments and results are given on models that consider flux changes resulting from cyclic barometric pressure pressure variations.

DESIGN FOR BETA RADIATION PROTECTION IN THE MINING  
AND MILLING OF HIGH GRADE URANIUM ORE

BY: (1) J.R. Mernagh (2) D.B. Chambers  
(1) Faculty of Medicine, University of Toronto  
(2) SENES Consultants Limited, Toronto

Uranium mine and mill workers are exposed to external gamma and beta radiation fields as well as receiving internal exposure. In the past the average uranium content of ore found in Canada and the United States has ranged from 0.1% to 1.0%  $U_3O_8$ . Historically, the resultant external exposures due to the mining and milling of such ore is relatively insignificant (1) as compared to internal exposures. More recently it has been concluded that the skin dose to body dose is likely less than two to one (2). Notwithstanding these observations, the development of high grade uranium mines in Northern Saskatchewan indicates that a re-evaluation of the importance of external exposures in the design of mine and mill facilities is appropriate. Some of these ore bodies have an average ore grade of 1% to 5%  $U_3O_8$  or greater.

This paper provides easy to use techniques for evaluating potential external beta radiation fields from the mining and milling of high grade ores. Recognizing that surface contamination of mine vehicles can be significant (e.g. 3) procedures for estimating beta doses from this uniform sources are also provided.

REFERENCES:

- (1) Federal Radiation Council, September 1967, "Guidance for the Control of Radiation Hazards in Uranium Mining", Report Number 8, Revised.
- (2) Utting, et al, "Investigations of Personnel Beta and Gamma Dosimetry Results at AMOK Ltd., Cluff Lake", Atomic Energy Control Board INFO-0034, June 1981.
- (3) Miller, H.T. and Scott, L.M., "Radiation Exposures Associated with Exploration, Mining, Milling and Shipping Uranium", Radiation Hazards in Mining, Manual Gomez, ed., 1981.

Wednesday, October 17, 1984 - Session 8a 09:30-12:00 (cont'd)

COMPUTER MODELING OF AIRBORNE ALPHA RADIATION IN MINES

BY: (1) K.R. Notley (2) A.J. Wheeler  
(1) Mining Engineering Department, Queen's University  
Kingston, Ontario, Canada  
(2) Dome Mines, Ontario, Canada

This paper describes the main features of VENTRAD, a computer program which models radon-related contamination in the air of a mine ventilation network. Input to the program consists of the network geometry, the airflow distribution, the dimensions of the airways and the radon emanating characteristics of the rock types involved. Output from the program consists of the radon concentration, the radon daughter concentration, the equilibrium ratio, and the volumetric age of the air throughout the network.

Used in conjunction with a conventional mine ventilation network analysis program which establishes a flow distribution, the program clearly illustrates a number of features concerning radon-related contamination which are not obvious from the application of radon growth theory to individual airways. The interrelation of contamination levels in various airways under different ventilation strategies may be studied. It is possible to simulate point sources of contamination and the effects of leakage and short-circuiting of air currents. The program also helps one appreciate the significance of other radiation parameters throughout a ventilation network besides the working level values normally measured.

Use of the program is illustrated through a series of examples involving subsections of an operating uranium mine.

EVALUATION OF A MICROCOMPUTER SYSTEM FOR CONTROLLING  
AND MONITORING RADIATION HAZARDS IN URANIUM MINES

BY: C.T. Sheeran, J.C. Franklin  
U.S.A.

A microcomputer-based monitoring and control system was evaluated for overall reliability, capability, and accuracy during two field tests in active uranium mines. The system was interfaced to continuous radiation monitors for both WL and radon concentration studies. It was also set up to monitor the position of airdoors, the operational status of fans, and the velocity of air in drifts. The system was used to control both primary and secondary ventilation fans, and tested successfully in automatically turning on and off these fans at specified times. Alarm capabilities of the system were used to alert ventilation engineers of undesirable radiation concentrations on both absolute value and rate conditions. Radiation records generated by the system compared very favorably to grab samples taken by mine personnel over the course of an entire test. Also, computer generated data was used to quantitatively estimate the release of radon to the atmosphere through an exhaust borehole.

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INSTRUMENTATION

EROS - "ELECTRONIC" RADON OBSERVATION SYSTEM

BY: Martti Annanmäki, Eero Oksanen  
Institute of Radiation Protection, Finland

To be able to measure long period mean radon concentrations in mines and other dusty environments cheaply and accurately, we have constructed a radon monitor called EROS. The function of EROS is based on radon diffusing into a collection chamber where charged RaA-atoms are electrostatically collected on an aluminum foil. On the backside of the aluminum foil there is a collimator which collimates the alphas from RaC' before they reach a cellulose nitrate film. The diameter of the hemispherical collection chamber is 100 mm, the collecting voltage between the walls of the hemisphere and aluminum foil is 30 V and the diameter and the length of the collimator are 10 mm and 20 mm, respectively. When reaching the cellulose nitrate film, the alphas have the energy of about 2.3 MeV. After a measurement period of about one month, the film is etched in 10% NaOH for 170 minutes, the temperature of the etchant being 60 °C. The film reading is performed using a microscope or microfiche reader. The response of EROS depends on the collecting voltage and the relative humidity of the air. The voltage of 30 V was chosen for regular use. The relative humidity has to be measured or estimated. The minimum detectable concentration of EROS in one month period is about 1 pCi/l (40 Bq/m<sup>3</sup>). The collimation and partial absorption of the energy of the alpha rays cause them to traverse the cellulose nitrate film perpendicularly and to have about the same energy, making the holes to be counted regular in shape and size.

MINE TESTS OF A PASSIVE ELECTRET DOSIMETER FOR  
RADON/THORON DAUGHTERS

BY: A. Khan, C.R. Phillips  
Department of Chemical Engineering and Applied Chemistry  
Toronto, Ontario

The properties of permanently charged electret foils in collecting radon daughters were examined in the laboratory. Based on the results of these experiments, a passive radon daughter dosimeter was designed. Six of these dosimeters were then exposed in a Canadian uranium mine in two separate tests for periods of up to five days. In the second mine test four out of six dosimeters performed satisfactorily. Electrets in the two remaining dosimeters were damaged accidentally during the test period. This paper describes the design of the electret dosimeter and presents results of the two mine tests. Finally, the future of passive electret dosimetry is discussed.

AUTOMATIC DISCRIMINATION AND READ-OUT OF TRACKS OF RaA  
AND RaC, on CR 39 USING IMAGE ANALYSIS

BY: H.L. Pai  
R.A.D. Service & Instruments Ltd., Toronto

In 1983, at the 7th International Conference on Solid State Dosimetry, we reported (1) that the tracks of RaA and RaC' in a CR39 detector can be readily separated by means of size discrimination. At this meeting, we will report the latest development of the automatic discrimination and read-out of the tracks of

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RaA and RaC' on CR39 using conventional electronic image analysis equipment. By the use of a micro computer and appropriate software and interfacing, the Working Level can be automatically calculated. At present, the sample changing and focus require manual operation, but these functions may eventually be automated. The significance of this work is that it makes possible a very simple single collimator design of the personal dosimeter for uranium miners. This new design will be much less complex and considerably cheaper than existing models using Kodak pathe LR115 type II detectors.

#### REFERENCE

- (1) H.L. Pai, J.H. Aitken, R. Stacy and P. Duport, "Alpha Energy Sensitive Devices for Dosimetric Purposes" paper presented at 7th Inter. Conf. on Solid State Dosimetry, September 1983, Ottawa.

#### A PASSIVE INTEGRATING RADON DOSIMETER COMBINING ACTIVATED CHARCOAL AND TLD

BY: Erling Stranden  
National Institute of Radiation Hygiene  
Norway

A passive integrating radon dosimeter is described. The dosimeter is based on radon absorption on activated charcoal. By placing TLD-crystals inside the charcoal container, the beta radiation from radon daughters, produced by decay of absorbed radon, is detected continuously during the exposure time. After closing the container, radiation will still be detected by the TLD. Calibration procedures are reported and the suitability of the dosimeter is discussed. The charcoal/TLD method is superior to the traditional charcoal method because the radiation from the charcoal is continuously detected during the whole exposure time. Furthermore, by the use of the charcoal/TLD combination, the decay time is not critical. In fact, the sensitivity is increased during the decay time when the exposure time is short. The dosimeter is suitable for postal delivery, the handling is very straight forward, and it is cheap and reusable. The useful exposure time ranges from a few days until perhaps two weeks.

#### ACTIVATED CARBON FILTER PAPER METHOD FOR THE MEASUREMENT OF RADON AND THORON CONCENTRATION

BY: W. Ri-Kai, L. Hongquan  
W. Sheng-De, M.C. Wang, M.X. Tian  
People's Republic of China

This paper describes a new method which is designed for quick measurement of the concentration of radon and thoron in uranium and thorium mine or mill atmospheres. This method is based on that the activated carbon filter paper has a strong ability of absorbing airborne radon and thoron, and its saturated absorptivity is proportional to the concentrations of radon and thoron in atmosphere. Air sample is drawn through the activated carbon filter paper at a flow rate of 10 l/min for 10 minutes. Five minute countings are made after the start of 5 and 13 minutes respectively. Using these counts we can determine the radon and thoron concentrations. With this method the lower limits of 0.74 Bq/l ( $2.10^{-11}$ ci/l) and 1.11 Bq/l ( $3.10^{-11}$ ci/l) can be obtained for radon and thoron measurement. A portable instrument based on this method has been used commercially. It can give a concentration value in 18 minutes with a digital display.



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DOSIMETRY

A REVIEW OF THE DOSIMETRY FROM INHALATION OF  
LONG LIVED ALPHA ACTIVITY IN ORE DUST

BY: J.R. Johnson  
Atomic Energy of Canada Limited  
Chalk River, Ontario, Canada

The IAEA has recently recommended (1) that the equation

$$\frac{I_{I,d}}{50} + \frac{I_{RnD}}{0.02} + \frac{I_{ThD}}{0.06} + \frac{I_{ODU}}{1700} + \frac{I_{ODTh}}{200} \leq 1$$

be used to limit the radiological hazard to miners in uranium and thorium mines. The first three terms in this equation represent external gamma irradiation and radon and thoron daughter exposures while the last two represent exposures to aerosols of uranium and thorium ore dust. The annual limits of intake (ALI) of 1700 Bq for long lived alpha activity of uranium and thorium ore dust respectively were calculated from models and parameters developed (2) for use with industrial compounds normally encountered in the workplace, and may not be adequate for ore dust. In addition, the limits for radon and thoron daughters used in the above equation are based, at least in part, on the regional lung concept (3) (with the TB and P region each assigned a weighting factor of 0.06), whereas the ALI's for ore dust are based on the composite lung concept (2) (with a weighting factor of 0.12).

Since the ALI's for ore dust are potentially very important in the estimation of the radiological hazards, and for monitoring programs in mines, it was decided to review the models and parameters that were used to calculate them. This paper presents the results of this review, with emphasis on the main uncertainties in the calculations, and gives the results of calculations using different models and parameters, and of using the regional dose concept.

- (1) IAEA Safety Series No. 26 (1983), IAEA, Vienna.
- (2) ICRP Publication 30 (1979), Pergamon Press, Oxford.
- (3) ICRP Publication 32 (1981), Pergamon Press, Oxford.

CONCENTRATIONS OF <sup>210</sup>Pb IN URANIUM MINERS' LUNGS AND  
ITS STATE OF EQUILIBRIA WITH <sup>238</sup>U, <sup>234</sup>U, and <sup>230</sup>Th

BY: Narayani P. Singh, David Bennett  
McDonald E. Wrenn, Salt Lake City, Utah

The concentrations of <sup>210</sup>Pb were determined in eight former uranium miners' lungs, in which the concentrations of <sup>238</sup>U, <sup>234</sup>U, and <sup>230</sup>Th were already determined. The concentrations of <sup>210</sup>Pb were higher than the concentrations of <sup>238</sup>U, <sup>234</sup>U, and <sup>230</sup>Th in all the lungs. This suggests that there are additional sources of intake of <sup>210</sup>Po and <sup>210</sup>Pb in addition to uranium ore dust in uranium miners' lungs. Three probable additional sources could be (1) inhalation of radon gas, (2) inhalation of short lived radon daughters, and (3) direct inhalation of <sup>210</sup>Po and <sup>210</sup>Pb present in the mine air from decay of <sup>222</sup>Rn.

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Concentrations of  $^{210}\text{Pb}$  ranged from 17 to 3333 pCi/kg wet weight, with a mean of  $886 \pm 1063$  pCi/kg. Since most of these uranium miners (all but two) died ten to twelve years before the analysis of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  all the  $^{210}\text{Po}$  present in their lungs at the time of death must have decayed by the time the analyses were performed. The concentration of  $^{210}\text{Po}$  in the lungs of the two miners who died in 1982 is almost equal to  $^{210}\text{Pb}$ .

These results suggest that the concentrations of  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  may be seven times higher than those of the parent isotopes  $^{238}\text{U}$ ,  $^{234}\text{U}$ , and  $^{230}\text{Th}$  in uranium miners' lungs. These findings may assist in formulating more accurate assessments of radiation doses to uranium miners' lungs from the  $^{238}\text{U}$  series.

Pb-210 CONCENTRATIONS IN THE BLOOD OF GROUND WORKERS AND  
UNDERGROUND MINERS OF ZINC-LEAD MINE

BY: T. Domanski, J. Doniec, W. Chruscielewski  
Institute of Occupational Medicine  
Poland

The investigations of Pb-210 concentration in the blood of 140 underground miners and of the 80 ground workers, non-miners, were conducted in "Boleslaw" Mining Centre. The aims of investigations were:

- to find the levels of Pb-210 in the blood of non-miners in the different age subgroups and,
- to study whether the exposure of miners to radon progeny can be correlated with the levels of Pb-210 when the break between exposure and measurements cannot be done i.e. when the miners are still actively working.

In summary two conclusions can be drawn, namely -

1. the mean concentration of Pb-210 in the blood of non-miners in the industrial region in Poland being 30 pCi/liter seems to be constant across the age groups and confirms the values found in the United States and Sweden;
2. the use of Pb-210 as a bio-indicator of miner exposure is probably valid even if the break between exposure termination and blood sampling is not feasible.

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URANIUM BEARING PARTICLES IN MINERS' AND MILLERS' LUNGS\*

BY: (1) A.S. Paschoa\*\*, M.E. Wrenn, N.P. Singh, S.C. Miller  
(2) K.W. Jones, M. Cholewa, A.L. Hanson (3) G. Saccomanno  
(1) University of Utah, Salt Lake City, Utah  
(2) Brookhaven National Laboratory, Upton, Long Island, New York  
(3) St. Mary's Hospital, Grand Junction, Colorado

The size distribution of uranium-bearing particles in air particulates in occupational areas of active uranium mines and mills is largely uninvestigated. Investigation of the size of residual uranium-bearing particles in uranium miners' and millers' lungs is warranted because significant inhalation of uranium can occur in certain occupational areas. Average uranium concentrations of about 0.3 ppm U in uranium miners' and millers' lungs have been reported. Local uranium concentrations in uranium-bearing particles inhaled and regionally deposited in the lungs of uranium miners and millers are orders of magnitude larger than the average uranium concentrations reported. The feasibility of using microPIXE (particle induced x-ray emission) techniques to search for such uranium-bearing particles embedded in lung tissues has been demonstrated. Proton microbeams 20  $\mu$ m in diameter, scanning in 5  $\mu$ m steps, were used to irradiate sections of lung tissues 10 to 40  $\mu$ m thick. The paper will briefly describe the method, and present and discuss the results obtained in an extensive search for uranium-bearing particles embedded in lung tissues, collected at autopsy, of former uranium miners and millers.

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\*\* On leave from Pontificia Universidade Catolica, Depto. de Fisica, C.P. 38071, Rio de Janeiro, RJ 22453, Brazil.

MEASUREMENT AND DOSIMETRY OF LONG-LIVED ALPHA EMITTERS IN  
URANIUM MINE ATMOSPHERES

BY: (1) N.H. Harley (2) Isabel M. Fisenne  
(1) New York University Medical Center, New York, N.Y.  
(2) U.S. Dept. of Energy, New York, N.Y.

Low flow rate, filtered-air samples were collected in uranium mines in New Mexico and Colorado by the U.S. Bureau of Mines for the purpose of investigating a one month integrating personal monitor. These samples were generously made available to us for the measurement of long-lived airborne particulates. Members of the uranium series have been analyzed isotopically after radiochemical separation of uranium, thorium, radium and lead. Data are presented on the particle size of airborne particulates, the degree of equilibrium for these uranium series members and the alpha dose received by target cells in the bronchial airways.

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VENTILATION/ENGINEERING

DEVELOPMENT OF A JOINT LABOUR-MANAGEMENT SAFETY INSPECTION  
SYSTEM AT DENISON OPERATION

BY: Denison/USWA (Canada)

This paper outlines the development of a concept in a joint approach to safety inspections at Denison operations, resulting from an agreement reached between Management and Labour in 1981. A retrospective review of Safety and Labour Relations dynamics within the Internal-Responsibility System is provided. Outline of an evolving organizational structure and safety performance being realized at the workplace is discussed.

1983: ONE YEAR OF INDIVIDUAL DOSIMETRY IN FRENCH MINES

BY: S. Bernhard\*, J.F. Pineau\*, A. Rannou\*\*, P. Zettwoog\*  
\*IPSN/DPT, \*\*IPSN/DPS  
Commissariat à l'Energie Atomique  
Fontenay-aux-Roses, France

The integrated system of individual dosimetry developed by the CEA for uranium mines has been presented at the Golden Conference in October 1981. It has become legal in France.

Since January 1, 1983, the 1 700 miners in French mines are furnished with this dosimeter that supplies the monthly potential individual exposures to polonium 214, 212 and radon 222, from which the exposures to the potential alpha energy of radon 222 and 220 daughters are derived. Ambient monitoring in operation till the end of 1982 has now been given up.

On the 18 700 results expected, less than 1% have been lost because of various failures.

The improvements effected in the dosimeter, peripheral reading out and operation are described.

A comparative analysis is made between the dosimetric data obtained in 14 underground mine sites and 10 open pit mines. The 1982 results of ambient monitoring are compared with the 1983 results of individual dosimetry. Finally, the structure of the cost price of individual dosimetry is analyzed.

LARGE-SCALE EXPERIMENTAL PERSONAL ALPHA  
DOSIMETRY IN CANADIAN URANIUM PRODUCING FACILITIES

BY: P.J. Duport and S. Ching  
Atomic Energy Control Board  
Ottawa, Canada

All uranium producing companies operating in Canada are participating in a limited 3-year experimental personal alpha dosimetry program. The program will take about 18 months to complete. With the exception of one company, where all radiation workers have a personal alpha dosimeter, 10% of the exposed work force participate to the experiment. The time integrating Personal Alpha Dosimeter

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(PAD) used in this program has been designed and produced by the French Atomic Energy Commission (CEA). The dosimetry program uses about 400 PADs, and is conducted in parallel with the regulatory dosimetry procedures. Dosimetry data obtained from regulatory methods and PADs are compared. To date, the data obtained confirms previous experiences: there is no correlation between individual exposures measured by regulatory methods and PADs; there is a discrepancy between the collective exposures measured by regulatory methods and PADs; PAD exposures distribution follow a log-normal distribution (which is generally not true for regulatory dosimetry data). In addition, the CEA-PAD measures separately exposures to Radon daughters, Thoron daughters and radioactive long-lived dust. The possibility for measuring exposure to  $\text{SiO}_2$  has been investigated successfully. The experiment also indicates ways to improve the presently available instrumentation.

#### THE DYNAMIC THEORY OF CLUSTERS

BY: M.J. Hawrynski

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This theory allows to predict the behaviour of positive ions, especially positively charged radon decay products in the ambient humid air. For positive ions attract water molecules very strongly, they surround themselves with water forming envelopes called clusters. Interaction type dipol-charge is dominating. The theory allows to calculate a cluster diameter as a function of the relative air humidity, the temperature and the pressure. The diffusion coefficient of clusters and the time of cluster forming can be calculated too. The main conclusions of the theory are as follows:

- the diameter of cluster is  $13 \cdot 10^{-10}$  for relative humidity 1% to  $23 \cdot 10^{-10}$  m for 100%;
- the cluster diameter depends strictly on the relative humidity. Fluctuations of the cluster diameter are from 1.5% to 1.6% /one standard deviation/ or 1 to 4 water molecules /40 - 220 water molecules form cluster/;
- the time of forming clusters is shorter than  $10^{-3}$ s;
- the diffusion coefficient of neutral radon decay products /about  $0.1 \text{ cm}^2/\text{s}$ / and is  $0.0096 \text{ cm}^2/\text{s}$  for 100% relative humidity and  $0.0224 \text{ cm}^2/\text{s}$  for 1% relative air humidity.

#### ELECTRICAL PROPERTIES OF RADON DAUGHTERS

BY: Niels Jonassen

Laboratory of Applied Physics I  
Technical University of Denmark

The short-lived airborne radon daughters may exist as ions being singly charged and having mobilities in the same range as ordinary small atmospheric ions.

These radon daughter ions may thus be affected by an electric field, e.g. deposit on oppositely charged insulating surfaces or collected by suitable electrode arrangements.

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VENTILATION/ENGINEERING

The paper reports some results of an investigation of the effects of electric fields on airborne radon daughters. The collection efficiency for radon daughters of metal discs kept at various potentials above ground are determined in atmospheres of different aerosol concentrations.

The relation between the fractions of unattached and charged radon daughters is also investigated. The results seem to indicate that a surprisingly high fraction (50% or more) of all three short-lived radon daughters may be affected by an electric field. It is still not clear, how these results relate to the fraction of the daughters being charged.

Also reported are preliminary results of controlling the level of radon daughters in a room by exposing the air to the field from various electrode systems. This method has the advantage of not increasing the unattached fraction when removing the activity from the air.

TECHNIQUES FOR MULTIVARIATE STATISTICAL ANALYSIS  
OF DOSIMETRY DATA FOR URANIUM MINERS

BY: (1) M.R. Phillips, A. Harrison-Stewart (2) R. Auty  
(1) Western Australian Institute of Technology  
(2) Ranger Uranium Mines PTY Ltd.  
Northern Territory Australia

1. INTRODUCTION AND DESCRIPTION OF DATA

Data covering a period of approximately three years were used for a multivariate statistical analysis. The main variables considered included: personal dust exposure measurements, time of exposure, occupational status and activity of worker, and methods of sampling and analysis. Additional variables which were incorporated into the analysis concerned climatic factors and factors relating to production.

2. AIMS AND OBJECTIVES

The aims of the study were to perform a statistical description of the data in order to:

- (a) examine the history of exposure in relation to factors which might be expected to influence the occurrence of high exposures;
- (b) aid decision-making with regard to statistically significant high exposures;
- (c) determine more efficient sampling strategies based upon multivariate analysis of the predictor variables for high exposure;
- (d) devise data-based 'action' limits in order to allow high exposures to be investigated systematically;
- (e) develop easy-to-use methods for routine decision-making within the plant.

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### 3. METHODS

Multiple analysis of variance and multiple regression techniques were used, utilizing the Statistical Package for the Social Sciences. The data were found to follow the expected log-normal frequency distribution, and thus the other variables were related to the natural log-rithm of the exposure measurement. The methods of analysis allowed a predictive model to be developed which identified factors which contributed to variation in exposure and also allowed those variables to be weighted in terms of their contribution to the variation. In addition, factors could be tested for statistical significance.

### 4. OUTCOMES

The analysis demonstrated that it was possible to develop more efficient sampling strategies and that those could be used to define plant-based 'action' limits. A data-management package was developed so that exposure measurements could be routinely stored and related to action limits and ICRP limits.

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DOSIMETRY

REVIEW OF GAMMA AND RADON DAUGHTER EXPOSURES OF  
URANIUM MINE WORKERS IN 1982 AND 1983 IN TERMS OF THE  
PRESENT AND PROPOSED AMENDMENTS TO THE AEC REGULATIONS

BY: S.H. Ching and K.P. Ho  
Atomic Energy Control Board  
Ottawa, Canada

The Gamma and Radon Daughter Exposures of Canadian Uranium Workers are analysed using statistical techniques. The results are presented in tabulated and graphic forms. These results are then reviewed in terms of the present AEC Regulations and the proposed Amendments to the AEC Regulations. The results of the review are discussed in detail in the text.

A COMPARISON OF METHODS FOR MONITORING MINER EXPOSURE  
TO RADON DECAY PRODUCTS

BY: D.W. Dixon, J.C.H. Miles and A.D. Wrixon  
National Radiological Protection Board, Chilton, Didcot,  
Oxon OX11 0RA, UK.

Exposures to radon decay products in some mines in the UK routinely exceed three-tenths of the ICRP recommended limit and in some cases the limit itself. At present, area monitoring using active air-sampling techniques is carried out in such mines to assess both miner exposure and the general mining environment. As the concentrations of radon decay products vary widely within a mine and vary with time at any particular place, estimates of individual exposure may be subject to large uncertainties. Personal monitoring of miners would reduce these uncertainties, and the amount of effort associated with the assessment of individual exposures.

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A comparison between personal and area monitoring techniques in the assessment of worker exposure was carried out in a tin mine. Miners were issued with two types of personal dosimeter: one constructed by the NRPB using CR-39 plastic for monitoring radon, the other manufactured by CEA for monitoring radon decay products. The concentrations of radon decay products to which miners were exposed were calculated from the results for the NRPB staff. Data on the occupancy patterns of the miners were used in the assessment of exposures and the results were compared with those obtained by personal monitoring. This paper will present the results and a discussion of this comparison of methods of monitoring miner exposure to radon decay products.

THE ESTABLISHMENT OF A NATIONAL CALIBRATION CENTRE FOR  
PRACTICAL STANDARDS FOR BIOASSAY AND IN VIVO MONITORING

BY: M. Limson-Zamora and C. Pomroy  
Radiation Protection Bureau  
National Health and Welfare

The Radiation Protection Bureau has long recognized the need for the standardization of measurements used in establishing dose estimates made for the purpose of radiation protection. The Bureau has thus initiated, maintained and administered intercomparison programs for bioassay and in vivo monitoring.

In March 1983, the Atomic Energy Control Board designated the Bureau to act as Canada's national calibration centre for bioassay and in vivo monitoring, with the mandate to provide internal dosimetry standards. Sincethen, the Bureau has been involved in placing its already ongoing quality assurance programs on a formal basis. Thus, for the uranium urinalysis intercomparison program which the Bureau initiated in 1978, the sample analysis schedule and the statistical evaluation of results have been restructured to better assess such attributes of performance as bias, between-lab variability and within-lab variability. Since analytical techniques do vary among participating laboratories, the Bureau has also initiated a study relating performance to methodology. Trends identified from the data obtained in this study will be reviewed. Progression of performance, assessed in terms of accuracy of results, is followed over a period of several intercomparisons.

For in vivo calibrations, a number of phantoms are available for uranium, thorium, and some iodine isotopes. Others are being developed.

Intercomparison programs that the Bureau plans to establish and administer for other bioassay measurements, as well as participation of the Bureau in international intercomparisons will also be discussed.

A FLEXIBLE COMPUTER MODEL FOR RADON DAUGHTER  
EXPOSURE HEALTH RISK ASSESSMENT

BY: M.E. Ginevan  
U.S. Nuclear Regulatory Commission  
Washington, DC

Evaluating the level of lung cancer risk associated with a given level of radon daughter exposure is a complex matter. There is the basic question as to whether one's risk assessment should apply absolute risk models (which principally



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consider the amount of radon daughter exposure) or relative risk models which consider both amount of radon daughter exposure and baseline lung cancer risk). Even when a general model form has been selected, there are decisions as to the exact form of risk projection and the appropriate method of accounting exposure over time. Apart from these uncertainties, there is a question as to how much personal habits such as smoking can modify risk.

This paper presents a computer model for general analysis of radon risks which allows the user to specify a large number of possible models with a small number of simple commands. The model is written in a version of BASIC which conforms closely to the American National Standards Institute (ANSI) definition for minimal BASIC and thus is readily modified for use on a wide variety of computers, and in particular, microcomputers.

My presentation illustrates the use of this model through a number of examples which include examinations of the effects of model selection, smoking status of the population at risk, and exposure regime on radon daughter health risk assessments.

#### THORON DAUGHTER TO RADON DAUGHTER RATIOS IN MINES

BY: Erling Stranden  
National Institute of Radiation Hygiene  
Norway

The ratio, potential alpha energy concentration of thoron daughters to potential alpha energy of radon daughters has been studied in 4 non-uranium mines. Two of the mines were situated in a thorium rich Norwegian area, the Fen area. In the "normal mines", the ratio ranged from about 0.04 to 0.8. In one of the mines in the Fen area, the ratio ranged from 15 to 30 with a mean value of about 30. The dose contribution from thoron daughters is discussed from the ICRP conversion factors. In normal areas, thoron daughters generally contributes only to about 10% of the effective dose equivalent from inhaled short-lived alpha energy. In thorium rich areas, however, the thoron daughters may dominate strongly, and in some cases, more than 90% of the effective dose equivalent could be caused by thoron daughters.

#### EVALUATION OF RADIOLOGICAL HAZARDS ASSOCIATED WITH MINERAL SANDMINING

BY: G.C. Mason, M.B. Cooper, S.B. Solomon,  
Australian Radiation Laboratory  
Yallambie Vic 3085, Australia

Mineral sand is mined primarily for its ilmenite, rutile and zircon content which yields a rich source of titanium and zirconium products. However, rare-earth minerals may also be present, including monazite which contains up to 7% thorium -232. Although the monazite fraction typically may be only a few hundredths of a percent of the raw sand, physical concentration during mineral separation may lead to hazards associated with the radioactivity of thorium and its daughter nuclides.

The primary exposure mechanisms are external gamma radiation, inhalation or ingestion of monazite dust and inhalation of thoron daughters. The familiar hazards associated with the uranium -238 series of radionuclides may also be present to a lesser degree.

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An evaluation of the radiological risks involved in the processing of mineral sands is made in the context of field measurements made at mineral sandmining sites in Western Australia. Experimental results indicate that while gamma radiation fields may be as high as 50  $\mu\text{Gy/hr}$  (5mR/hr) at isolated points in a separation plant, monitoring and control is easy to effect, and further that thoron daughter concentrations are typically below  $2 \times 10^{-8} \text{ Jm}^{-3}$  (lmWL).

An assessment is made of the experimental problems involved in measuring radioactivity in dusts at the concentrations encountered in the field, particularly in relation to measurements of the activity median aerodynamic diameter (AMAD) required for estimation of whole-body effective dose equivalent.

Finally, the various exposure pathways are considered in relation to the total radiological hazard associated with mineral sandmining.

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EPIDEMIOLOGY

POTENTIAL CO-CARCINOGENS IN THE URANIUM MINE ENVIRONMENT  
PART II - POTENTIAL INTERACTIONS AMONG WORKPLACE CONTAMINANTS

BY: (1) D.B. Chambers and C.A. Adkins (2) R.E. Marchant  
(1) SENES Consultants Limited, Toronto  
(2) Consultant in Occupational Medicine, Saskatoon

Studies of increased incidence of lung cancer in uranium miners have focussed on the relationships between lung cancer and miners' exposure to radon daughters and smoking. However, the miner populations are known to have been exposed also to other agents that are potentially carcinogenic or co-carcinogenic.

Parts I and II of this paper examine the possibility of co-carcinogenic interactions among substances potentially encountered in uranium mine and mill atmospheres.

Uranium miners are exposed to a complex and variable assortment of airborne substances. In addition to interaction between radon daughter exposure and cigarette smoking, the potential exists for interactions involving other substances, such as diesel exhaust, free silica, uranium and other materials (e.g. As, Co, Cr, Fe, Ni, V, Y, Zn and their compounds) in airborne dust.

A literature search was conducted for data on human responses to these and other potential uranium mine atmosphere contaminants, as well as for models of carcinogenic mechanisms. Available studies on human populations were reviewed for indications of interactions in the development of lung carcinogenesis. In published epidemiologic studies there is essentially no dose-response data for chronic exposure to any of these substances except radiation and cigarette smoke. In most studies, occupational exposures were rarely assessed beyond the observation that a certain contaminant was known to have been present in the workplace environment. The carcinogenic nature of individual constituents was documented, as was available evidence of potential interactions.

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STUDIES OF GRANTS, NEW MEXICO, URANIUM MINERS

BY: J.M. Samet, M.V. Morgan, A.A. Valdivia, C.R. Key  
University of New Mexico, Albuquerque, New Mexico  
and Grants Clinic, Grants, New Mexico

This study focuses on the health effects of uranium mining on Grants, New Mexico, miners. Production began in this area in the 1950's; and throughout the 1960's and 1970's, New Mexico was a leading uranium producer. Cumulative exposures sustained by earlier New Mexico uranium miners were well below those on the Colorado Plateau, and more recent miners have had even lower exposures, limited by Federal standard to 4 Working Level Months (WLM) annually. Cohort mortality studies of two separate groups are in progress: a retrospective study of an already selected group of 3,055 miners with first underground experience presumed to be before 1971; and a prospective study of miners first exposed from 1971 on. We are evaluating feasibility of the latter study by examining company exposure records from 1967 through 1982. Preliminary analyses suggest that 10,000 miners are available for investigation. For both groups, company physical examinations supply mining and smoking histories. Company and state records provide data for estimation of WLM. Follow-up of the earlier cohort through 1978 has now been carried out. This presentation will describe the study's methodology, mortality results in the earlier cohort, and the feasibility of the cohort study of later miners.

IMPACT OF OCCUPATIONAL HAZARDS ON THE LIFE EXPECTANCY OF  
URANIUM MINERS

BY: D.K. Myers and J.R. Johnson  
Health Sciences Division, Atomic Energy of Canada Limited  
Chalk River Nuclear Laboratories,  
Chalk River, Ontario, Canada.

The biological hazards associated with energy production appear to be much smaller than the benefits derived in terms of life expectancy. This is true not only for the general population but also for workers in most portions of the nuclear power industry. However, uranium miners represent a critical subgroup in which occupational hazards are sufficiently high to affect their average life expectancy appreciably. Depending upon the exposures to various sources of radiation in a given uranium mine, the potential loss of life expectancy due to radiation exposures may approach that due to fatal occupational accidents. Potential genetic risks due to radiation exposures in the mine are expected to be very small and undetectable.

UPDATE OF THE UNITED STATES PUBLIC HEALTH SERVICE  
URANIUM MINERS COHORT STUDY

BY: Robert J. Roscoe, M.S.  
U.S. National Institute for Occupational Safety & Health

The United States Public Health Service began a cohort mortality study of uranium miners in 1950. The last published report, with mortality follow-up for white miners through 1977, revealed standardized mortality ratios of 482 for lung cancer, 499 for certain nonmalignant respiratory disease, 409 for tuberculosis, 262 for chronic nephritis and, 331 for accidents. Since these

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results were presented in 1981, research on this cohort has continued. An analysis of white cohort members who never smoked cigarettes with mortality follow-up through 1977 is nearing completion. This analysis looks at lung cancer risk as a function of cumulative exposure to radon daughters rather than length of employment. It also uses a correction factor to derive the expected number of lung cancer deaths among nonsmoking uranium miners. Available results will be presented. Also underway is a joint National Institute for Occupational Safety & Health/National Cancer Institute project containing a questionnaire survey to update mining and other occupational exposures and medical and smoking histories for all cohort members. This questionnaire survey is intended to provide the data for final calculations of lifetime exposures to radon daughters for virtually all cohort members. These calculations will be used to determine which miners received lifetime exposures of less than 120 working level months (WLM). Analysis of these miners will help NIOSH make recommendations on the adequacy of the present U.S. exposure limit of 4 WLM per year which corresponds to 120 WLM over a working lifetime of 30 years. Progress will be presented.

INCIDENCE & DEVELOPMENT OF LUNG CANCER DUE TO CIGARETTE  
SMOKING AND RADIATION EXPOSURE IN URANIUM MINERS

- BY: (1) Geno Saccomanno, Ph. D., M.D. (2) Coralee Yale, M.S., &  
Wilfrid Dixon, Ph. D. (3) Oscar Auerbach, M.D.  
(1) St. Mary's Hospital & Medical Center, Grand Junction, Colorado, USA  
(2) UCLA School of Medicine, Los Angeles, California, USA  
(3) Veterans Administration Medical Center, East Orange, New Jersey, USA

A large population of uranium miners has been studied since 1957. The objective was to determine how tumors of the lung develop cytologically over time. The carcinogenic effect of radon daughter exposure (WLM) and cigarette smoking was also correlated.

It was found that some cancers of the lung develop gradually over a long period of time. This was demonstrated by sputum studies on an annual and semi-annual basis. The metaplastic cells found in sputum progressively become more and more atypical, and finally give rise to cancer. It takes about 10 years for epidermoid cancer to develop.

The study group included 185 uranium miners who developed lung cancer. Smoking history, exposure to radiation (WLM), and tumor type were documented on each miner. One case of lung cancer was found in the non-cigarette smokers exposed to 1-300 WLM, while 4 cases were found among the smokers. The group exposed to 301-1000 WLM yielded 2 lung cancer cases in the non-cigarette smokers, and 36 in the cigarette smokers. Uranium miners with 1001-2000 WLM exposure developed 5 lung cancer cases in the non-cigarette smokers, and 30 in the cigarette smokers. The group receiving over 2001 WLM exposure yielded 17 cases of lung cancer in the non-cigarette smokers, and 45 in the cigarette smokers.

A slight increase in small cell cancers was found among the heavy cigarette smokers who were exposed to large doses of radiation.

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SEX RATIO OF FIRST-BORN CHILDREN  
OF UNITED STATES URANIUM MINERS

BY: Robert J. Roscoe, M.S. and Richard J. Waxweiler, Ph.D.  
U.S. National Institute for Occupational Safety and Health  
Victor E. Archer, M.D.  
Rocky Mountain Center for Occupational & Environmental  
Health

Change in the sex ratio (male births over female births of offspring may be one of the mutagenic effects of radiation exposure in parents. The U.S. Uranium Miners Cohort, a group who received both alpha and gamma whole body radiation, was used to test this hypothesis. Data on 2,803 first births among the uranium miners were analyzed. At the presumed date of conception, two radiation exposure variables were calculated for each father: 1) the average annual working level (WL) for radon daughters in the mine he worked, and 2) his cumulative working level months (WLM) of exposure to radon daughters. The WL were divided into exposed and unexposed, and the WLM were divided into unexposed, 1-119 WLM, and 120 WLM or greater. When fathers of all ages and races were considered together, the overall sex ratio was 1.08 and there was no trend with cumulative WLM exposure. However, when the births were divided at the father's median age at conception (24 years), the sex ratio tended to decrease with increasing WLM for the younger group (1.03, 1.09, 0.80) and increase with increasing WLM for the older group (1.07, 1.26, 1.47). These age-specific tendencies were observable for both whites and American Indians. The same age-specific tendencies were noted when the data were divided into the two WL categories. Various genetic and nongenetic interpretations of these results will be discussed.