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RADIATION MONITORING OF URANIUM MINERS:

A COMPARISON OF BIOASSAY, TLD, AND THE KUSNETZ DETERMINATIONS OF CURRENT EXPOSURES

by Keith J. Schiager and Noel F. Savignac

Department of Radiology and Radiation Biology
Colorado State University

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May 1972

by

Keith J. Schiager

and

Noel F. Savignac

Department of Radiology and Radiation Biology
Colorado State University
Fort Collins, Colorado 80521

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Chapter 1

INTRODUCTION

I. Health Problems Associated with the Mining of Uranium

Uranium technology is an integral part of the nuclear age. The peace-time requirements for increasing quantities of electrical power are a necessary outgrowth of an expanding population aspiring for an ever higher standard of living, but with the dwindling supply of economically available fossil fuels, nuclear reactors are being constructed to supply an increasing proportion of the electrical power requirements. In 1961 the federal government contracts for the purchase of uranium caused the uranium mining industry to reach its peak, but in the early seventies the government's procurement contracts have diminished to nothing because of the decreased military requirements for uranium. The current slump in the uranium mine industry will, however, undergo a slow reversal as the country's electrical requirements continue to increase. Thus the health problems associated with the industry will continue in conjunction with the continuing needs for uranium.

A health problem unique to the presence of uranium in any type of underground mining operation is the increased probability of lung cancer in comparison to the probability for the general population. Radon (^{222}Rn) gas is a natural decay product of uranium. The inert gas diffuses from uranium bearing deposits, aided by the flow of water, and infiltrates the working areas of a mine. The decay products of radon are illustrated in Figure 1.1. All of the decay products are present in the underground atmosphere, but the short-lived radon daughters are believed to be the principle causative agents of lung cancer in uranium miners. The terms working level (WL) and working level month (WLM) have been formulated to express concentrations of radon progeny mixtures in air and cumulative exposure to these airborne materials, respectively. The working level is defined as "any combination of radon daughter products in a liter of air which will result in the ultimate emission of 1.3×10^5 million electron volts of potential alpha energy" (Hearings, 1969). The derivation of the numerical value

Figure 1.1. Radon (222) decay scheme

is presented in Table 1.1 and represents the total alpha particle energy released by the decay through Ra-C' of the short-lived radon daughters in equilibrium with 100 picocuries (pCi) of ^{222}Rn . The working level month is defined as an exposure to 1 WL for 170 hours (one work month).

II. Objectives

The accurate determination of working levels and working level months is of considerable medical importance in the prevention of lung cancer attributed to the inhalation of, and subsequent energy deposition from, the short-lived radon daughters. The objective of the research undertaken and reported in this publication was to quantitatively compare and establish correlations between three different methods of determining exposures:

1. periodic air sampling and exposure-time estimation in specific working areas of a mine,
2. individual-miner air sampling with a thermoluminescent dosimetry (TLD) air sampler, and
3. bioassay sampling for long-lived radon daughters in whiskers and blood of uranium miners.

The first two methods rely on the measurement of alpha activity from the short-lived radon daughters in the mine atmosphere. Both of the methods are purely physical determinations of working levels. The third method requires the inhalation of radon and the radon daughters prior to determinations of the long-lived daughters in biological tissues. The short half-lives of Ra-A, Ra-B, Ra-C, and Ra-C' exclude their determination in any bioassay procedure. Gotchy (1968) demonstrated a correlation between average working levels and Ra-D or Ra-F specific activities in hair and in blood samples. The relationships he presented will not be derived but their applicability to a different uranium mining situation will be determined. Subsequent to the check of the bioassay system, the three methods for the determination of working level months will be compared.

Table 1.1. Definition of the working level unit (after Evans, 1969, and McCurdy, 1969)

Nuclide	Alpha Particle Energy Per Disintegration (MeV)	Number of Atoms Per 100 pCi	Alpha Energy Available in Decay of Each Atoms Through RaC' (MeV)	Total Alpha Energy Per 100 pCi	Fractional Contribution to the Working Level Unit (at equilibrium)
Radon (Rn-222)	5.49	1.77×10^6	excluded	excluded	
RaA (Po-218)	6.00	977.	$6.00 + 7.68$	0.134×10^5	.105
RaB (Pb-214)	0	8580.	7.68	0.659×10^5	.515
RaC (Bi-214)	0	6310.	7.68	0.485×10^5	.380
RaC' (Po-214)	7.68	$1. \times 10^{-3}$	7.68	0.000×10^5	
Total				1.278×10^5	
In round numbers				1.3×10^5 MeV/l	

III: Bioassay Procedures for the Determination of Working Level Months

Bioassay procedures for the determination of exposures from short-lived radon daughters may be placed in one of two categories:

1. the determination of cumulative working level exposures as a result of mining experience several years prior to the bioassay determinations, and
2. the determination of current levels of exposure for individuals actively involved in mining.

Bone samples have been used to determine cumulative exposure but the bioassay procedures usually have the disadvantage of requiring bone samples either from a bone biopsy or from a deceased miner. A correlation between working level months and Ra-D specific activity in bone was established by Black (1968) and slightly modified by Holtzman (1970). Eisenbud et al., (1969) solved the problem of requiring samples of bone by means of a CsI(Th) crystal optically coupled with a NaI(Th) crystal for in vivo counting of the 47 keV gamma-ray from Ra-D. The method had, however, a lower detection limit of a 4 nCi Ra-D body burden which represents an estimated 800 WLM.

The Ra-D content in urine samples has been correlated with cumulative exposures to short-lived radon daughters, but the correlation is only applicable to those individuals who have not been engaged in the mining operations for the past 3 to 10 years (Cohen and Kneip, 1969). Estimates of the current levels of exposure through the measurement of Ra-D in urine have not yet been possible (Gotchy, 1968; Cohen and Howell, 1969; and Archer, 1969).

Hair or whiskers offer possibilities as biological indicators of current exposures to short-lived radon daughters. Each portion of a hair reflects the blood concentration of Ra-D at the time of its formation (Archer, 1969). Ra-D firmly attaches to the sulfhydryl groups of the precursors of keratin and, once incorporated into the hair, the Ra-D atoms are not reabsorbed (Widdowson, 1964). Jaworowski (1969) has reported the specific activity of Ra-D in hair from a non-mining population to be 0.041 pCi per gram and from a uranium mining population to be 0.225 to 1.51 pCi per gram. Gotchy (1968) demonstrated a correlation between both Ra-D and Ra-F in whisker clippings and the

average working levels to which the miners were exposed. Blood was the only other tissue that appeared feasible for the development of a bioassay system. Gotchy (1968) concluded that neither urine nor fecal bioassay would be of value in the evaluation of current occupational exposures to uranium miners.

IV. A Comparison of Monitoring Methods

The higher incidence of lung cancer in white uranium miners than in the general population has provided motivation for the development of many systems to monitor the radiation exposure received by uranium miners. Currently the uranium mine companies in the United States comply with the Federal regulations by obtaining periodic air samples and estimating a miner's time of exposure in specific working areas of a mine. Such a system provides exposure determinations on a group basis and is subject to inaccurate estimation of a miner's exposure due to possible selective air sampling or other systematic sources of error. Thus, in an attempt to provide information on a possibly superior monitoring system, comparisons have been instituted between the mine-company determinations of exposure, personal TLD determinations of exposure, and the bioassay determinations of exposure. The procedure for the establishment of such comparisons is presented in the materials and methods section of this report.

Chapter 2

MATERIALS AND METHODS

The description of the research and development of a bioassay procedure for uranium miners has been divided into four sections. The first section describes the collection of data by biological and physical methods. Section II is concerned with the processing of biological samples, section III with the determination of sample activity, and the last section is concerned with data analysis.

I. Data Collection by Biological and Physical Methods

A) Project Organization and Data Collection

The Ambrosia Lake basin near Grants, New Mexico, was selected as the study area for the following reasons: The area represents one of the larger mining operations in the United States. Secondly, the geology of the New Mexico mines, 0.2 percent uranium oxide as carnotite in alluvium sandstone, differed from the granitic schist of the Schwartzwalter Mine near Golden, Colorado. The latter mine was the site of Gotchy's pilot study (1968) upon which the bioassay determinations in the New Mexico mines are based. The selection of mines in a different geological formation provided an opportunity to test the validity and applicability of Gotchy's results in a different mine environment. Arrangements were made with the Kerr McGee Mining Company and with the United Nuclear Homestake Mining Company to obtain the cooperation of 10 miners from each of four mines; mine section numbers 17 and 24 for the former company and mine section numbers 23 and 25 from the latter. Subsequent reference to the mine companies will be by numbers, reference to the mine sections will be by letters and reference to individual miners will be by number to avoid any unwarranted criticism directed towards specific companies, mines or individuals. Included in the sample of miners participating in this study were five individuals of Spanish-American ancestry, i.e., miners' numbers 4, 28, 31, 32 and 39. Miners were selected on the basis of admirable work records and a desire to cooperate with the biological and physical

monitoring procedures. As a control group, 10 individuals were selected from the Grants, New Mexico, area based on their residency in the area for at least 10 years, and a history of employment in occupations other than mining. Replacements for miners and controls were selected as needed to maintain a study group of 40 miners and 10 controls. Information concerning the health, smoking, and employment histories of each participant was obtained through the use of a questionnaire presented in Figure A.1 of appendix A and the results of the questionnaire are summarized in Table A.1. The specific instructions issued to each participant in the study are presented in Figures A.2, A.3 and A.4.

Mine-company ventilation engineers collected weekly whisker samples from each participating miner and at 10-day intervals the dosimetry components of his personal TLD system. Record maintenance and issuance of necessary supplies for the continued operation of the study at each mine site were likewise handled by the ventilation personnel. To assist in the correction of specific problems arising at each mine as pertains to this project, personnel from Colorado State University conducted five trips to the Grants area. The whisker samples were forwarded by mail to Fort Collins, Colorado, as well as the various components of the TLD system for analysis, repair and replacement. The individuals serving as controls mailed in their whisker samples regularly and were contacted on each of the five trips to the area. As an incentive for cooperating in the study each miner was presented with a new hard hat, part of which had been modified to hold a portion of the TLD system, and a new electric razor⁽¹⁾ for the collection of whisker samples. The controls received only the electric razor. For the miners and controls willing to give monthly, 15 ml blood samples, arrangements were made with the Grants Clinic of Grants, New Mexico, to obtain and forward the heparanized blood samples. For each blood sample submitted the miner or control received \$2.50 and the Grants Clinic received \$1.00.

B) Description of the Thermoluminescent Dosimetry System

The description of the personal TLD system, its calibration and the issuance procedures have been reported by McCurdy (1969) and

(1) Norelco Speedshaver

by Schiager (1969), and are summarized as follows:

The dosimetry system consists of a personal air sampler and a filter holder containing the dosimeters. As illustrated in Figure 2.1, the personal air sampler is attached to the miner's equipment belt near the lamp battery, and the filter holder containing the thermoluminescent dosimeters (TLD's) is mounted on the miner's protective hat by a steel spring clip. A piece of 1/4 inch I.D. tygon tubing connects the filter holder to the pump and is attached to the miner's lamp cord by several pieces of plastic spiral cable wrap. Two sets of "Luer-lok" connectors, one at the pump and the other at the protective hat permit removal of the lamp cord and tubing from the dosimetry system for nightly recharging of the miner's lamp battery.

1) Description of the filter holder unit

The filter holder assembly is a combination of a modified 1/2 inch diameter filter holder and two 1/2 inch diameter thermoluminescent (TL) dosimeter discs separated by a steel washer. The components of the filter holder assembly are illustrated in Figure 2.2. The atmosphere to be sampled enters the top of the filter holder, passes through the 3 mm diameter hole in the center of the TL discs and the steel washer and is filtered by a 0.65 micron porosity membrane filter. The 0.65 micron pore size provided the maximum air flow rate without significant degradation of the alpha energy due to penetration of aerosols into the filter medium.

The filter holder assembly can be divided into two discrete dosimeters, the working level-liter dosimeter and the gamma-ray dosimeter. The working level-liter dosimeter, or alpha exposure dosimeter, is the TL disc mounted on the teflon seal ring above the filter paper. This TL disc is directly exposed to the alpha and beta particles originating from the decay of the nuclides collected by the filter paper. In addition to the exposure from the nuclides on the filter paper the TL disc is also exposed to external gamma-rays penetrating the brass filter holder. The external gamma-ray dosimeter is the TL disc positioned above the steel washer in the filter holder. The working level-liter response is attained by subtracting the response of the gamma-ray TL dosimeter from the total response of the alpha dosimeter. A 1 mm thick steel washer, placed between the two TL discs, absorbs the energetic beta particles penetrating the alpha dosimeter TL disc.

2) Thermoluminescent materials

Three thermoluminescent materials - $\text{CaSO}_4:\text{Mn}$, LiF , and $\text{CaF}_2:\text{Dy}$ were investigated as possible alpha dosimeters to be utilized in this personal monitoring system. The TL materials were uniformly distributed throughout the teflon matrix having a disc configuration with dimensions of 0.4 mm thickness x 12.5 mm

Figure 2.1. Radon progeny personal dosimetry system as worn by a miner. Filter holder on hat connected by tygon tubing to battery-powered air sampler on belt.

Figure 2.2. Filter holder and thermoluminescent dosimeter assembly. Disassembled and assembled views.

diameter ⁽¹⁾. The TL material represented 28 percent of the weight of the teflon disc. The fact that the TL material was embedded in the inert teflon support medium does not change the fundamental properties of the TL materials. The disc was not required to be as thick as 0.4 mm for alpha dosimetry, but the thicker medium provided the dosimeter with better support in the filter holder as well as during readout. The application of $\text{CaF}_2:\text{Dy}$ in the personal monitor was initiated after the thermoluminescent characteristics of the material were investigated (and reported in section V of McCurdy's report).

Before using the dosimeters, it was necessary to modify the TL teflon discs by the following procedure:

1. Upon receipt of the TL-teflon discs, a 3 mm hole was punched in the center of the disc by a specially adapted paper punch.
2. The TL discs were coded by numbering each disc with a hard lead pencil. The graphite marking is not readily removed by abrasions and is insoluble in solvents normally used to cleanse the discs.
3. The coded discs were dipped in trichloroethylene to remove any dirt or body oils which may have accumulated during handling. This procedure must be diligently followed, for dirt and oils luminesce when heated, thus producing inaccurate readings.
4. The discs were simultaneously annealed and flattened by heating them on a flat aluminum pan at a temperature of 325 C for 15 minutes.

3) Personal air samplers

Casella personal air samplers were used to draw air samples through the filter medium of the filter holder assembly unit. The pump unit shown in Figure 2.1 was a constant volume displacement diaphragm type pump driven by a constant speed D.C. motor. The motor was powered by a rechargeable 900 milliampere-hour capacity, 7.5 volt nickel cadmium battery. The number of motor revolutions, which is directly related to the volume of air sampled, was measured by a visible stroke counter attached to the motor's drive shaft via a worm gear. The complete unit was enclosed in a white, high-impact plastic case having the physical dimensions of 5 x 3 1/2 x 2 1/4 inches and weighing approximately 21 ounces. The small size of the pump enabled it to be carried in a pocket or to be attached to the miner's battery belt.

Sampling was initiated by completing the electrical path from the battery to the motor through inserting a male plug into a metal socket on the top of the case, (or by closing a switch on the side of subsequently modified air pumps). The female socket was wired to enable the enclosed battery to be charged by a similar plug connected to the charging unit.

(1) LiF and $\text{CaSO}_4:\text{Mn}$ teflon dosimeters were obtained from Isotopes Incorporated as stock items. Upon request, Isotopes Incorporated uniformly mixed $\text{CaF}_2:\text{Dy}$ powder (Harshaw Chemical Co. small mesh-code number 2-1-6) into a teflon matrix.

To enable the pump unit to operate for a week without the inconvenience of daily battery recharge and to reduce the mechanical wear of the pump's moving components, a solid state electronic timing circuit was incorporated into the pumping unit. The timer permits the sampler to operate in an on-off cyclic manner with a duty cycle of approximately 15 percent, i.e., an "on" time of three seconds and an "off" time of 16 seconds. The timer circuit, as illustrated in Figure 2.3 incorporates two 2N1274 (NPN) transistors as a basic astable multivibrator and a 2N1304 (PNP) transistor as an emitter follower. Although the on-off time periods of the multivibrator section are principally dependent upon the values of the transistor base resistors and capacitors, the internal collector-to-base resistance of the transistor also affects the timing cycle.

An assembled timing circuit is shown in Figure 2.4. The completed circuit board, having dimensions of 1.25 x 0.875 x 0.435 inches, was positioned between the motor and the case enclosure.

The stroke of the diaphragm pump (and, therefore the work load of the motor) was adjusted to obtain 90 milliamperes of current through the motor while sampling air through a 0.65 micron porosity membrane filter. Under a continuous current drain, the charge life of the battery was greater than eight hours, i.e., one working day. If the pump was operated in the cyclic mode, the battery life was extended to at least 45 hours. The current drain of the battery and the duty cycle of the pump were coordinated to permit the operation of the pump for five, eight hour days without the necessity of battery recharge. The battery was charged over the weekend rather than nightly.

4) Battery charger

A battery charger was designed and constructed to recharge ten air sampler batteries simultaneously. The unit will recharge the batteries in a period of 14 hours at a current of 90 mA per battery. A voltmeter was provided in the charger unit to test the condition of each of the ten batteries individually by means of a rotary selector switch. Connection to the batteries is accomplished through ten individual electrical cables equipped with plugs that mate with the socket on the air samplers.

C) Calibration and Response of the TLD System

1) Air flow rate calibration

The diaphragm pumps were calibrated with a four liter spirometer in terms of volume sampled per digit recorded on the stroke counter. Since the working level is defined in terms of alpha energy (MeV) per unit volume of air, the total volume of air sampled must be known before the average working level-hour exposure can be estimated. The total volume of air sampled by the pump is the product of the number of pump strokes, obtainable from the difference between the ending and starting readings of the stroke counter, and a calibration factor expressing the volume sampled per pump stroke.

Q₁ and Q₂ - 2N1274 transistors
 Q₃ - 2N1304 transistor
 M - pump motor

Figure 2.3. Timing circuit schematic. The circuit controls cyclic operation of the personal air sampler.

Figure 2.4. Personal air sampler with timing circuit

Although the total volume of air was used to determine the average working level, an error would be introduced in the calculated exposure value, if the sampling flow rate did not remain constant throughout the entire sampling period. If the flow rate changed significantly during the sampling period, the resulting exposure would be a weighted average, placing more emphasis on the atmospheric conditions at the time the flow rate was the greatest.

The variability in flow rate of ten Cassella pumps, five operating in the continuous mode and five operating in the cyclic mode, was measured as a function of operating time. The flow rate of the pump was measured by a calibrated capillary tube-manometer system. The capillary tube was calibrated in terms of differential pressure drop across the capillary tube as a function of flow rate. As with all pump calibration procedures, an assembled filter holder was inserted in the intake line to simulate actual sampling conditions.

The experimental results, presented in Table 2.1, indicate that the variability of flow rate as a function of time was insignificant in most instances. The data clearly showed that the pumps operated in the continuous mode for eight hours and in the cyclic mode greater than forty hours, without substantial change in flow rate.

2) Effect of dust loading on filter air flow resistance

Prior to issuance and subsequent to use, the pressure drop across the filter holder at a flow rate of 0.5 liter per minute was measured for each batch of filter holders sent to the mines. During the early period of the study the variability of the pressure drop between filter holders within a given batch was found to be large. This variability was attributed to air leaking around the threads of the filter holder and bypassing the filter medium. The air leakage problem was alleviated by applying Dow Corning Silastic sealant to the threads of the filter holders. In addition to preventing air leaks in the filter holders, the sealant aids in determining if the filter holders have been opened or tampered with in any manner.

Analysis of 172 samples which had been sent to and received from the mines revealed that there was no significant change in pressure drop due to dust loading. The average pressure drop across the filter holders sent was 20.2 ± 1.8 inches of water whereas the average pressure drop across the filter holders received was 21.6 ± 3.18 inches of water. Since the confidence bands of the two data means overlap, it was concluded that there was no significant change in air flow resistance caused by dust loading of the filters during use.

3) TLD response to radon progeny

The response of CaF_2 :Dy teflon discs to radon progeny was measured in terms of TL output as a function of the WL-liter or latent alpha energy exposure. The measured exposure was the alpha energy stored in the TL material as a result of the decay of the short-lived daughters in a specific volume of air. For example, if one liter of air containing radon progeny concentration of one

Table 2.1. Flow rate of the Casella pumps as a function of time

Cyclic Operating Time (Hours)	Flow Rate (liters per minute)					Continuous Operating Time (Hours)	Flow Rate (liters per minute)				
	Pump A	Pump B	Pump C	Pump D	Pump E		Pump F	Pump G	Pump H	Pump I	Pump J
0	0.17	0.35	0.35	0.44	0.38	0	0.37	0.20	0.42	0.45	0.31
12	0.17	0.35	0.35	0.44	0.38	1	0.37	0.20	0.42	0.45	0.31
17	0.17	0.35	0.35	0.44	0.38	2	0.37	0.23	0.42	0.45	0.31
20	0.17	0.34	0.35	0.44	0.38	3	0.37	0.23	0.42	0.45	0.31
36	0.18	0.34	0.35	0.44	0.38	5	0.37	0.23	0.42	0.44	0.31
38.5	0.18	0.34	0.35	0.44	0.36	6	0.37	0.23	0.42	0.44	0.31
40.5	0.18	0.34	0.35	0.44	0.37	7	0.37	0.23	0.42	0.44	0.31
44	0.18	0.34	0.35	0.44	0.37	8	0.37	0.23	0.42	0.44	0.31

working level was drawn through the filter holder, the latent alpha particle energy from the decay of the short-lived radon progeny would be 1.3×10^5 MeV, representing a cumulative detector exposure of one WL-liter. Although the radon progeny exposure of the TL dosimeter was expressed in units of latent alpha energy, the dosimeter was actually exposed to a mixture of alpha particles, beta particles and gamma-rays from the decay of the radon progeny. Therefore, the total energy deposited and stored as F centers within the TL material was composed of the energy deposited by the corpuscular radiations traversing the material. McCurdy (1969) found that the fraction of the thermoluminescent response contributed by alpha particles of ^{218}Po and ^{214}Po was 0.79. The alpha particle response was obtained by comparing the thermoluminescence from TL discs exposed to membrane filters, covered with aluminum absorbers to remove the alpha particles, to the thermoluminescence from TL discs exposed to uncovered filters. The remaining TL response from the beta particles of ^{214}Po and ^{214}Bi was nearly constant and independent of the equilibrium conditions existing in most uranium mine atmospheres. The ratio of beta to alpha disintegrations was 1.5 for a typical mine atmosphere having activity ratios of 1.0, 0.4, and 0.2 for ^{218}Po , ^{214}Pb , ^{214}Bi , respectively. The beta to alpha emission ratio was also 1.5 for an atmosphere containing radon progeny in transient equilibrium. Variations in the radon daughter activity ratios normally found in uranium mines did not change the beta to alpha emission ratio by more than 10 percent, corresponding to a 2 percent change in the beta response of the TLD.

To evaluate the response of the TL materials to radon progeny several dosimeters were exposed by sampling through the filter holder various volumes of air containing known radon progeny concentrations. The WL concentration of the sampled atmosphere was determined by the alpha spectroscopic technique described by Martz, *et al.*, (1969). Subsequent to sampling termination, the filter holder assemblies were set aside for four hours to allow the complete decay of the short-lived daughters collected on the filter. The TL discs were then removed from the filter holder and annealed at 115 C for 10 minutes. The TL discs were read out by the Harshaw TL analyzer and the measured thermoluminescent output was recorded. The average TL output of several unexposed TL discs was recorded as a background response and subtracted from the response of the exposed TL discs.

The calibration results are shown graphically in Figure 2.5. As a matter of convenience, two abscissa scales are shown, one expressing the exposure in units of latent alpha energy and another which expresses the exposure as working level-liters. Linear regression equations were developed from the calibration data. The statistical results indicated that the response of the TL materials was a direct function of the detectors' exposure as expressed in latent alpha energy or WL-liters.

The minimum detectable exposure for the $\text{CaF}_2:\text{Dy}$ dosimeters was approximately one WL-liter. Below the WL-liter exposure level, the variability in the TL response of $\text{CaF}_2:\text{Dy}$ becomes large because

Figure 2.5. Response of CaF₂:Dy teflon dosimeters to radon progeny collected on a membrane filter with an air sampler.

the inherent thermoluminescence of the dosimeter contributes a significant portion of the total TL response, a response equivalent to 1.8 ± 0.65 WL-liters. Since the inherent background of the dosimeters varied by ± 70 percent⁽¹⁾, subtraction of the background response of exposures less than one WL-liter led to great inaccuracies. Consequently, exposures greater than 10 times the equivalent inherent exposure of the dosimeters are desirable to minimize the variability of response associated with low level exposures. The maximum detectable exposure for the $\text{CaF}_2\text{:Dy}$ dosimeters was greater than 10^4 WL-liters.

4) TLD response to external gamma-rays

External gamma-ray exposures to uranium miners depend upon the grade and quantity of ore within the mine. Preliminary exposure measurements indicated that quarterly exposures of 300 to 600 mR might be typical for many miners. The use of thermoluminescent materials as gamma-ray dosimeters was already well established in other portions of the nuclear industry; it was natural, therefore, to use TLD's to measure external exposures to uranium miners.

To measure the sensitivity of the TL dosimeters to gamma-rays, eight brass filter holders, each containing duplicate or triplicate annealed $\text{CaF}_2\text{:Dy}$ teflon discs were exposed to a calibrated ^{226}Ra gamma-ray source. Secular equilibrium of all the progeny was assured since the source had been sealed more than two years earlier. The filter holders were placed at a distance of one-half meter from the ^{226}Ra source on a rotating turntable. The continuous rotation of the filter holders avoided a biased exposure of the enclosed TL discs. Exposure of the dosimeters to gamma-rays from various directions would produce a variety of TL responses because of the different degrees of gamma-ray absorption in the non-uniform thickness of the filter holder. The TL discs in the filter holders were exposed to six different exposure levels ranging between 17.8 mR and 329 mR. Subsequent to exposure, the TL discs were annealed at 115 C for 10 minutes. Two filter holders, each containing three dosimeters, were retained as background dosimeters. The average response of the six discs to background radiation was subtracted from the response of the TL discs exposed to the ^{226}Ra source.

Figure 2.6 is a graphical representation of the response of the dosimeters to gamma-rays. Through the use of a least square regression analysis, the linear equation of $Y = -0.133 + 16.5 X$ was developed from the measured data points. Y is the response of the dosimeter and X is the exposure in roentgens. The intercept of the derived equation was not significantly different from zero at the 68 percent confidence level. A correlation coefficient of 0.99 was obtained for the fitted equation.

(1) 68 percent confidence level.

Figure 2.6. Response of $\text{CaF}_2:\text{Dy}$ teflon dosimeters mounted in a brass filter holder to gamma-rays from an external ^{226}Ra source.

The response of the dosimeter corresponding to an exposure of 150 mR was found to be 10 times the inherent thermoluminescence of the $\text{CaF}_2\text{:Dy}$ teflon dosimeters. Thus, the accuracy of determining exposures greater than approximately 100 mR would be unaffected by the variability of the inherent TL of the dosimeters. The precision of estimating the response of exposures greater than 150 mR was better than ± 5.1 percent at the 68 percent confidence level and was increased to ± 4.0 percent at an exposure of 329 mR.

5) Reproducibility of the dosimetry system

It was assumed that the total response of the dosimetry system would have two sources of variation; the variation of response existing between individual TL dosimeters and the variation associated with the volume of air sampled by the individual air samplers. Variations existing between sequential annealing procedures was thought small and, therefore, neglected. The variability of response between individual dosimetry systems sampling the same radon progeny atmosphere was measured in the exposure tunnel at the Cotter Corporation's Schwartzwalder uranium mine. Fifteen separate dosimetry systems, each having dissimilar sampling rates, sampled volumes of air ranging between 2.66 and 156 liters from an atmosphere containing a radon progeny concentration of 34 WL. The atmospheric samples taken represented 28 individual WL-liter exposures. The response of the separate $\text{CaF}_2\text{:Dy}$ dosimeters was converted to its appropriate WL concentration and the mean and the coefficient of variation of the data set computed.

A separate experiment involving the variability of the $\text{CaF}_2\text{:Dy}$ -teflon dosimeters was also performed. Fifteen $\text{CaF}_2\text{:Dy}$ -teflon discs, selected at random, were exposed to 1.5 R of ^{137}Cs gamma-rays. The discs were annealed before and after exposure as previously described. The variability of the response of the dosimeters was measured by computing the coefficient of variation for the data set.

As shown by the results presented in Tables 2.2 and 2.3, the variability of response between individual TL dosimeters constitutes 36 percent of the overall variability. The degree of dispersion of the individually calculated WL concentrations and the response of the dosimeters was measured by the coefficient of variation. The variability of the response of the TL dosimeters and of the total system was measured as 0.036 and 0.10, respectively, at the 68 percent confidence level.

It must be noted that the variability of response between dosimetry systems was not a measure of the dispersion at a definite exposure but rather over a wide range of exposures. It is believed that the variability measurement for an exposure range is a more realistic representation of the true dispersion between responses of individual dosimetry systems.

6) TLD response to non-sampled radon and progeny

It was hypothesized that the TL dosimeters within the filter holder would be insensitive to airborne radon progeny not sampled by the system. To determine whether or not the dosimetry

Table 2.2. Variability of the complete dosimetry system

Volume Sampled (liters)	Response of the TLD in Alpha Energy (MeV x 10 ⁻⁷)	x (MeV/liter x 10 ⁻⁶)	Radon Progeny Concentration (WL)
156.	60	3.9	30.0
147.	70	4.7	36.2
135.	57	4.2	32.3
112.	56	4.9	37.7
109.	56	5.1	39.2
78.5	29	3.8	29.2
75.8	32	4.3	33.1
47.2	22	4.7	36.2
22.	8.2	3.7	28.5
20.3	8.2	4.0	30.8
9.4	4.1	4.4	33.8
8.5	4.1	4.8	36.9
8.4	3.4	4.1	31.5
7.93	3.6	4.5	34.6
7.83	3.8	4.9	37.7
7.63	3.9	5.2	40.0
7.61	3.5	4.6	35.4
7.32	2.9	4.0	30.8
6.85	3.2	4.6	35.4
6.5	3.0	4.6	35.4
6.2	2.4	3.8	29.2
6.2	2.7	4.3	33.1
5.33	2.2	4.1	31.5
5.2	2.0	3.9	30.0
4.32	2.1	4.8	36.9
4.2	1.5	3.6	27.7
3.34	1.5	4.6	35.4
2.66	1.1	4.1	31.5

Number of Data Points - 28

$$\bar{x} = 4.4 \times 10^6$$

Coefficient of Variation = 0.10

Table 2.3. Variability of the $\text{CaF}_2:\text{Dy}$ teflon discs as determined from an exposure of 1.5 R ^{137}Cs gamma-rays.

Response	Number of Data Points	Mean	Coefficient of Variation
45.3	15	46.7	0.036
47.7			
48.3			
45.0			
46.5			
47.3			
48.9			
46.9			
45.8			
45.8			
48.8			
46.6			
47.8			
42.4			
47.2			

system responded to non-sampled radon or radon progeny, six filter holder assembly units containing $\text{CaF}_2\text{:Dy}$ -teflon dosimeters were exposed to an atmosphere having a radon progeny concentration of 20 working levels. The units remained in the contaminated atmosphere for a period of 7.25 hours, accumulating an exposure of 145 WL-hours, equivalent to slightly less than one working level month. The response of the TL dosimeters within the filter holder units was compared to the response of the TL dosimeters within non-exposed filter holder units.

Statistically, the response of the six exposed dosimeters and the response of several background dosimeters were not significantly different at the 68 percent confidence level. In fact, the response of the exposed dosimeters were not statistically different from the inherent thermoluminescence of the $\text{CaF}_2\text{:Dy}$ -teflon dosimeters. Therefore, it was apparent that the response of the dosimeter would not be biased by non-sampled radon or radon progeny.

7) Long-lived alpha activity on monitor filters

Since the working-level-liter dosimeter within the filter holder unit responds primarily to alpha irradiation, any source of alpha particles other than radon progeny would produce a false WL-liter response. The main source of alpha activity on the filter paper, other than the radon progeny, would be the uranium ore contained in dust particles. To investigate whether or not the dust particles on the filter paper contained a sufficient quantity of uranium ore to result in an appreciable alpha activity, several filter papers were counted in a low background gas flow proportional counter. The results of 32 samples counted for 55 minutes are presented in Table 2.4.

In most instances (80 percent), the alpha activity on the filter paper was less than 1.5 disintegrations per minute. Of course, the activity measured upon receiving the filter holders was not the alpha activity existing on the filter paper during the entire sampling period at the mine. One could assume that if a person worked in the same area of the mine for the complete monitoring period, the rate of increase in the alpha activity would be constant and therefore the average activity for the monitoring period would be one-half the measured activity. However, this assumption is only valid if the ore grade and the ventilation remained constant during the monitoring period. Under the above assumption, a measured alpha activity of one disintegration per minute would correspond to a 0.9 WL-liter dosimeter exposure for a 20 day monitoring period. However, this exposure value is rather small compared to the radon progeny exposures found during the same monitoring period.

D) Issuance Procedures for the TLD System

1) Pre-issuance procedures

The filter holder units were prepared for use at mines by the procedure outlined below:

- a. The TL discs were washed in trichloroethylene and wiped dry with a Kimwipe disposable tissue. In

Table 2.4. Long-lived alpha activity found on monitor filters

Sample Number	Alpha Activity (dpm)	Volume Sampled (liters)
1	0.96	*
2	3.1	53
3	0	*
4	0.56	52
5	0.78	54
6	0.37	*
7	1.6	*
8	0.41	374
9	0	*
10	2.1	127
11	0.59	394
12	1.4	560
13	0.67	30
14	0.30	*
15	0.96	*
16	1.2	*
17	0.56	228
18	0	*
19	0.49	*
20	1.7	81
21	2.1	165
22	1.8	181
23	0.48	38
24	0.26	162
25	0.56	84
26	0.19	189
27	0.11	178
28	0.52	86
29	0.30	58
30	0.074	.043

* Volume not recorded.

addition to drying the discs, the tissue also removed any dirt which may have adhered to the surface of the discs.

- b. The teflon discs were then placed in an annealing furnace at 325 C for 15 minutes to remove any residual thermoluminescence. Following the appealing technique, the discs were cooled to room temperature by placing them on a lead brick heat sink.
- c. The filter holder number (monitor number) and the number of each TL disc to be used within the unit were recorded on the Readout Report form (Figure 2.7). The filter holder units were then assembled. The TL discs were positioned with the numbered side facing away from the filter.
- d. The threaded seams of the assembled filter holders were then sealed with Dow Corning Silastic Clear Sealer.
- e. After the sealant had dried, the pressure drop across the filter holders was determined at a flow rate of 0.5 liters per minute.
- f. Filter holders were then mailed to the participating uranium mines and issued to the miners by the mine officials. The units were worn by the miners for two weeks or half a month and then returned to the laboratory for exposure analysis.

2) Post-exposure procedure

Upon receiving the filter holder units from the mines, the following post-irradiation procedure was initiated:

- a. The filter holder identification number was recorded and checked against the list of filter holders that were sent.
- b. In order to determine if dust loading of the filter paper affected the pressure drop across the filter holder, the pressure drop across the filter holder was measured at 0.5 liter per minute.
- c. The filter holders were disassembled and the TL disc identification numbers checked against the numbers issued.
- d. The alpha activity on the filter paper was measured by counting the filter paper in a gas proportional counter.
- e. The TL discs were cleaned with trichloroethylene and annealed for 10 minutes at 115 C to remove the first two glow peaks.
- f. The TL discs were then read out on the thermoluminescent analyzer and the results recorded on the Readout Report form (Figure 2.7).
- g. The Silastic sealant which had been used to seal the thread seams of the filter holders was removed by placing the filter holders in a beaker of Freon TF solvent. This solvent causes the sealant to swell and pull away from the filter holder.

Colorado State University
Dept. of Radiology and Radiation Biology
Fort Collins, Colorado 80521

Readout Report on TLD Personal Monitors

Dosimetry Period _____ through _____ Date of Readout _____
 _____ mR/nCoul. _____ 10^6 MeV/nCoul.

I.D. Number	Monitor Number	Gamma Ray Response					Working Level - Liter Reponse				
		TLD No.	Gross	Bkg.	Net nCoul.	Exp. mR	TLD No.	Gross	Bkg + γ Res.	Net nCoul.	WL-1

Figure 2.7. Form used to record identification and analysis data for TLD monitors

E) Mine Company Area Monitoring

In compliance with the Federal government limitations of 1 WLM average exposure to radon daughters in the working areas of a uranium mine (Hearing, 1969)⁽¹⁾, the ventilation engineers from both mine companies regularly monitored the working areas of their respective mines. As a field method to determine the radon daughter concentrations, the mine companies utilized the Kusnetz (1956) method based on the alpha activity of the radon daughters filtered from a liter of air. The method specified a single count to be made between 40 and 90 minutes post-sample collection. By then Ra-A had decayed to negligible levels of activity and only Ra-C' remained on the filter as an alpha emitter. A zinc sulfide screen with a photomultiplier tube was used to obtain the concentration of Ra-C' and Ra-C. By assuming a given radon daughter equilibrium ratio, the WL concentration for a specific time and location in the mine was calculated. Multiplying the calculated WL by the fraction of the 170-hour work month spent in the location of measured activity allowed each mine company to determine for individual miners the WLM exposures presented in the results' section of this report. Obvious drawbacks of the Kusnetz method employed by the mine companies include assumptions regarding the radon daughter equilibrium ratio in each work area, and the application of WL determined in one area of a mine to a miner who may be working only part time in the measured area and part time in areas of different WL concentrations.

II. The Processing of Biological Tissues

A) Washing Procedure for Chemical Glassware

Fink (1950) has reported that Ra-F demonstrates an affinity for glass especially in neutral or basic solutions. As the levels of Ra-E and Ra-F to be determined in the study were in the order of picocuries, extreme care was exercised to segregate chemical glassware according to levels of sample activity and to clean the glassware after the processing of each sample. The flasks used for the chemical

(1) After January 1, 1971, the maximum allowable limit for exposure to radon daughters was revised to 2 WLM per quarter or 4 WLM per year.

digestions were divided into the following categories: 1) flasks used for control hair samples and blood samples, 2) flasks used for miners' hair samples, and 3) flasks used for spiked whisker and spiked blood samples. Depending on the specific needs in the laboratory, flasks could be moved up from categories 1 to 2 or from 2 to 3, but never in the reverse direction. The washing procedure for glassware in each of the three categories was as follows:

1. Glassware was washed in a hot aqueous solution of detergent⁽¹⁾ and rinsed with three aliquots of tap water.
2. Each item of glassware was rinsed with a solution of 15 ml nitric acid (70% HNO_3) and 15 ml of perchloric acid (70% HClO_4) followed by six deionized water rinses.
3. All glassware was air dried and stored for subsequent use.

The washing procedure for all components of the plating equipment was identical to the procedure presented above except for the deletion of nitric acid in step 2.

B) Sample Preparation Prior to Wet-Chemical Digestion

Blood samples were received monthly from the Grants Clinic in a nonrefrigerated, padded shipping container. Upon receipt, each sample was weighed and coded for future identification as to the date of collection and as to the individual donating the sample. Individual blood samples ranged in weight from 6 g to 16 g.

For each weekly whisker sample the collection date and name of the individual donating the sample were recorded. The weekly samples from each participant were usually combined into pooled monthly samples or if a combined sample was less than 0.1 g, additional weekly samples were added until a weight in excess of 0.1 g was attained. The total time period represented by each pooled whisker sample was recorded. The pooled samples were transferred to 50 ml beakers in preparation for washing to remove external contamination in the form of uranium ore dust, Ra-D, Ra-E, or Ra-F.

(1) Alconox detergent.

C) Washing Procedure for Whisker Samples

Uranium miners, while underground, are in continual contact with uranium ore in the form of dust and/or mud. Attached to the ore particles are atoms of Ra-D and Ra-F that would interfere with a whisker bioassay system. Thus the following washing procedure, presented schematically in Figure 2.8, was utilized to remove the external contamination from the whiskers:

1. Twenty-five ml of a saturated detergent solution⁽¹⁾ was added to each pooled whisker sample in a 50 ml beaker. The slurry was agitated in an ultrasonicator⁽²⁾ for 30 seconds.
2. The detergent solution was decanted from the whiskers using a stainless-steel, wire-mesh screen to prevent loss of the whiskers.
3. Another 25 ml of detergent solution was poured into the beaker through the metal screen to remove any whiskers adhering to the screen. The slurry was agitated in the ultrasonicator for 30 seconds.
4. Steps 2, 3 and 2 were repeated.
5. Ten ml of acetone was poured through the screen, to remove any whiskers adhering to the screen. The slurry was agitated for 30 seconds in the ultrasonicator.
6. The whiskers were filtered from the acetone wash with a filtering apparatus⁽³⁾ containing a 7 cm diameter filter paper⁽⁴⁾. Whiskers were then rinsed from the beaker and filtering apparatus with approximately 5 ml of acetone delivered from a squeeze bottle.
7. Each sample was air dried for a minimum of 4 hours, weighed, and transferred to a 250 ml Erlenmyer flask for wet ashing.

(1) Alconox detergent.

(2) Cole-Parmer ultrasonicator.

(3) Millipore filtering apparatus.

(4) Watman #1 filter paper.

WASHING PROCEDURE FOR HAIR

Figure 2.8. Block diagram of the washing procedure to remove external contamination from whisker samples.

The fraction of external contamination removed from the hair by the above washing procedure was determined using uranium ore dust as an external contaminant of hair tissue. Direct contamination of hair by exposure to radon daughters in a laboratory aerosol chamber did not produce measurable contamination as indicated by a 2 week exposure of hair to an atmosphere of 21 working levels. Thus the following procedure was used to determine the fraction of external contamination removed from hair:

1. Hair clippings, directly from a barber's apron, were obtained from a local barber shop.
2. The hair sample was cut, using hand shears, as finely as possible to simulate whisker tissue and mixed thoroughly with finely-pulverized, high-grade, uranium-ore dust. Only enough dust was used which would adhere to the hair.
3. Large dust particles were manually shaken from the hair in the process of dividing the sample into 20 aliquots of approximately 0.5 g each. Half of the samples were weighed; the remaining samples washed as outlined above and then weighed.
4. All samples were chemically digested, the Ra-E and Ra-F plated on nickel discs, and the activity of each nuclide determined.
5. Each determination was corrected for instrument background, counting geometry, detector efficiency, sample weight, and the observed specific activities of control samples, i.e., noncontaminated hair samples. The average Ra-E specific activity was 0.245 picocuries per gram (pCi/g) based on 7 control samples and the average Ra-F specific activity, based on 4 control samples, was 0.616 pCi per g.

For each category of hair tissue, i.e., washed and unwashed, the results, standard deviation of the items in each category and mean are presented in Table 2.5. For both Ra-E and Ra-F contamination the difference in means between the washed and unwashed samples was significant at the 0.01 level as determined by Students "t" test. Thus the removal of 85.2 percent of the Ra-E contamination ($\frac{17.285-2.552}{17.285}$) was considered adequate

Table 2.5

Specific activities in picocuries per gram of unwashed and washed hair samples contaminated with uranium ore dust, S.D. = standard deviation, $\bar{x}$ = sample mean, n = sample size, "t" (16 d.f.) = Student's "t" value for 16 degrees of freedom, H_0 = hypothesis, μ_1 = population mean.

pCi Ra-E/g Unwashed Hair Samples	pCi Ra-E/g Washed Hair Samples	pCi Ra-F/g Unwashed Hair Samples	pCi Ra-F/g Washed Hair Samples
33.384	1.000	8.683	0.000
14.257	2.334	11.567	1.436
21.026	2.907	10.543	0.009
15.300	2.880	10.375	11.130
17.669	1.940	14.428	1.115
15.694	2.372	9.955	2.055
11.858	2.309	16.086	13.907
19.298	4.675	9.579	6.919
12.285		19.373	
12.080		15.412	
S.D. = 6.451	S.D. = 1.046	S.D. = 3.512	S.D. = 5.418
$\bar{x}$ = 17.285	$\bar{x}$ = 2.552	$\bar{x}$ = 12.600	$\bar{x}$ = 4.714
n = 10	n = 8	n = 10	n = 8
$H_0: \mu_1 = \mu_2$ "t" (16 d.f.) = 7.106		$H_0: \mu_1 = \mu_2$ "t" (16 d.f.) = 3.806	
Significant at .001 Level		Significant at .01 Level	

justification for the routine incorporation of the washing procedure as a prelude to the chemical digestion of whisker tissue.

D) Wet-Chemical Digestion Procedures

The chemical procedures for the complete digestion of blood and hair tissue to the liquid ionic form were originally developed by Blanchard (1966) and modified by Gotchy (1968). The procedures as further modified for use in this study are presented in a block diagram in Figure 2.8, and are outlined as follows:

1) Blood samples

- a) Each 15 ml blood sample was weighed and transferred to a 250 ml Erlenmyer flask. The vacutainers, used for sample collection, were rinsed with three, 10 ml aliquots of deionized water to insure nearly complete transfer of the blood from the vacutainer to the flask.
- b) Ten ml of nitric acid (70% HNO_3) was added to each flask in an acid fume hood. The solution was brought to a slow boil on a hot plate ⁽¹⁾ until all particulate materials were dissolved.
- c) Thirty ml of perchloric acid (70% HClO_4) was added to each sample. The solution was brought to, and maintained at a slow boil until all of the nitric acid had evolved from the sample as evidenced by the production of dense, white, perchloric acid fumes. If a solution was heated to dryness, the flask was cooled to room temperature and 20 ml of deionized water was added to dissolve the residual salts in the flask. If the samples turned black an explosion was highly probable. Immediately, nitric acid was added ad lib., and the solution removed from the hot plate. If the sample did not explode, the flask was heated cautiously until all of the black particulate material was dissolved. Additional heat was supplied, slowly boiling the solution to expel the nitric acid. The samples that exploded were discarded from the

(1) Thermolyne hot plate model 2200.

CHEMICAL DIGESTION OF HAIR OR BLOOD

Figure 2.9. Block diagram of the chemical digestion procedures for hair and blood samples.

study whereas the samples possibly contaminated by the explosion were designated as such in subsequent calculations. If the calculated specific activities appeared higher than the mean of previously digested samples, the specific activity of the samples present at the time of an explosion were eliminated from all subsequent calculations. Otherwise the specific activities were considered valid determinations.

d) Each flask was cooled to room temperature and covered with a thin sheet of paraffin⁽¹⁾ until the sample could be plated.

e) The entire digestion procedure required approximately 10 hours for completion.

2) Whisker samples

a) Five ml of deionized water and 5 ml of nitric acid (70% HNO_3) were added to each flask containing washed, and pooled whisker samples; 15 ml of perchloric acid (70% HClO_4) was added to each flask after the whiskers were completely moistened by the dilute nitric acid.

b) Each sample was heated to, and maintained at, a slow boil until the solution was clear, colorless, and emitting dense, white, perchloric-acid fumes.

c) Each flask was cooled to room temperature and covered with a thin sheet of paraffin⁽¹⁾ for storage until sample plating.

d) The whisker digestion procedure required approximately 4 hours for completion.

E) Ra-E and Ra-F Plating Procedures

Upon completion of the wet-chemical digestion procedures, Ra-E and Ra-F were separated from blood and whisker samples by the plating procedures described by Blanchard (1966) and by Gotchy (1968). The procedures as modified for use in this study are presented below:

(1) Parafilm paraffin sheets.

1. Twenty-five ml of deionized water, approximately 200 mg of l-ascorbic acid, and two drops of a color indicator described by Fink (1950) was added to each digested whisker or blood sample. The indicator was prepared by combining 50 g methyl blue, 125 g bromothymol blue, 85 ml ethyl alcohol, and 15 ml deionized water. The indicator produced the following color-pH relationships:

<u>Color</u>	<u>pH</u>
red	below 5
orange	5
yellow	6
green	7
blue	above 7

2. A saturated solution of sodium hydroxide (NaOH) was added drop by drop into each sample until the sample was basic as indicated by a dark blue color. Hydrochloric acid (37% HCl) was added slowly until the sample appeared green, indicating neutrality. With blood samples a black feathery precipitate often formed but the color of the indicator could still be detected in the liquid phase. Four ml of hydrochloric acid (37% HCl) was added to each sample which dissolved any precipitate material present.
3. Each plating cell consisted of a 4 ounce polypropylene bottle⁽¹⁾, with the bottom removed, a 13/16 inch nickel disk, and a plastic cap with a cork insert. The nickel disk was coded for sample identification, placed between the cap and neck of the bottle, and tightened in place by firmly screwing the cap on the bottle. Each plating cell was inverted for use and leak tested with deionized water for a minimum of 10 minutes.
4. Each sample was transferred from the digestion flask to a plating cell. A minimum of six deionized water rinses of the digestion flask were added to the plating cell to produce a final, sample volume of 100 ml and a 0.5 N solution.

(1) Nalgene polypropylene bottle.

5. Up to a maximum of six plating cells were placed in an 80 C water bath⁽¹⁾. Each sample was stirred for 3 hours at 300 rpm with a polypropylene stirrer⁽²⁾ and an individual stirring motor⁽³⁾.

The temperature of the plating solution was determined to be 70 C due to the evaporative cooling induced by the stirring process. Deionized water was added to each sample as needed to maintain a sample volume of 100 ml for the duration of the plating process.

F) Recovery of Ra-E and Ra-F from Whisker Samples

The same Ra-D, Ra-E, Ra-F solution used by Gotchy (1968) was calibrated to determine the fraction of Ra-E and Ra-F recovered from digested and plated whisker samples. Table 2.6 presents the results of 37 samples air dried on nickel disks under an infrared heat lamp. The standard deviation of the items in each category, mean, number of samples, and coefficient of variation are presented for the Ra-E and Ra-F determinations. As will be described subsequently in the materials and methods section a low-background Geiger counter was used to detect the beta particles from Ra-E and a series of silicon surface-barrier detectors determined the Ra-F alpha activity. A minimum of 500 counts was accumulated for the Ra-E determinations and a minimal counting time of 10 minutes was used for the Ra-F determinations. The coefficients of variation calculated from the equations to be presented in the section on counting statistics indicate that for the Ra-E calibrations counting statistics account for 0.5 percent of the observed 8.5 percent coefficient of variation. For the Ra-F calibrations counting statistics account for 0.2 percent of the observed 12.8 percent coefficient of variation. A Ra-E to Ra-F ratio of 1.89 was observed using the Geiger counter and silicon detectors. The same ratio was observed by counting two of the

-
- (1) Lab-Line water bath model 3010-12.
(2) Nalgene polypropylene stirrer.
(3) Eberback power-stir model 58.

Table 2.6. Calibration of the Ra-D, Ra-E, Ra-F solution used to determine recoveries from chemically digested and plated biological samples, S.D. = standard deviation, $\bar{x}$ = sample mean, n = number of samples, c.v. = coefficient of variation.

Ra-E in pCi/ml		Ra-F in pCi/ml	
408.305	439.267	223.532	251.456
426.466	282.865	233.366	182.043
457.329	456.578	220.992	188.238
445.602	439.962	301.205	187.889
430.427	398.361	277.721	194.687
404.739	397.507	190.854	205.751
420.660	424.837	209.138	209.848
487.818	466.928	229.748	206.598
458.082	410.718	228.612	235.175
464.976	464.976	160.100	235.027
460.357	435.483	230.306	218.729
430.427	459.217	236.984	216.758
468.107	421.676	246.393	254.968
434.462	405.329	291.255	229.082
377.793	426.139	218.452	228.100
377.670	426.466	257.788	208.460
441.358	378.565	209.138	223.597
406.514	418.759	228.036	241.954
428.437		248.086	
S.D.	36.384	S.D.	28.948
$\bar{x}$	426.572	$\bar{x}$	225.949
n	37	n	37
c.v.	8.5%	c.v.	12.8%

samples in a 2π gas flow proportional counter⁽¹⁾. Theoretically, one would have expected a ratio of 1.00 due to a sample age of greater than 2 years, but as Fink (1950) suggests a plateout of Ra-F onto the side walls of the polypropylene container may account for a lower than equilibrium level of Ra-F.

The recovery of Ra-E and Ra-F from whisker samples was determined by spiking 1 gram samples of hair clippings obtained from a local barber shop with 0.200 ml of the standardized Ra-D, Ra-E, Ra-F solution. The 21 samples were then processed by chemical digestion and plating of the samples onto nickel disks as described above. The results of the Ra-E and Ra-F determinations are presented in Table 2.7. Dividing the mean recovery of Ra-E and Ra-F by the respective means for the standardized solution results in the fraction of each nuclide recovered from the digested samples, i.e., 0.742 for Ra-E and 0.723 for Ra-F. The coefficient of variation for the determination of Ra-E activity in the standardized solution was 8.5 percent as compared to 8.5 percent in the recovery experiment. The same comparison for Ra-F activity was 12.8 percent versus 14.9 percent. The similarity in magnitude of the coefficients of variation for each nuclide leads one to infer that the variability between the recoveries from digested whisker samples is either in the calibration of the spiking solution or in the pipetting procedure used to deliver the 0.200 ml aliquots of standardized solution to each hair sample. Gotchy (1968) found the coefficients of variation to be 29.3 percent for the recovery of Ra-E and 6.1 percent for the Ra-F recovery.

G) Recovery of Ra-E and Ra-F from Blood Samples

Table 2.8 presents the recovery of Ra-E and Ra-F from 15 ml blood samples spiked with 0.200 ml of the standardized Ra-D, Ra-E, Ra-F solution. The samples were chemically digested and plated as described above. The standard deviation, mean, number of samples, coefficient of

(1) Nuclear Associates 2π gas flow proportional counter Model #J4-138 with an Ortec Model #446 high voltage power supply, an Ortec Model #109PC preamplifier, an Ortec Model #485 amplifier, an Ortec Model #484 scaler, an Ortec Model #225 timer, and an Ortec Model #401A NIM bin and power supply.

Table 2.7. Recovery of Ra-E and Ra-F from 1. g hair samples spiked with 0.200 ml of the standardized Ra-D, Ra-E, Ra-F solution, S.D. = standard deviation, $\bar{x}$ = sample mean, n = number of samples, c.v. = coefficient of variation.

Recovery of Ra-E in pCi/ml of Spike Solution	Recovery of Ra-F in pCi/ml of Spike Solution
275.576	146.507
344.555	130.333
355.116	177.809
332.205	170.127
363.947	154.556
310.330	184.144
325.211	175.191
355.116	203.190
297.386	177.625
341.173	221.804
300.601	175.250
310.677	157.344
293.618	152.408
290.853	119.675
324.074	150.751
314.900	136.956
297.704	154.864
280.298	149.246
279.173	146.227
345.411	188.411
312.422	156.891
S.D. 26.895	S.D. 24.270
$\bar{x}$ 316.683	$\bar{x}$ 163.300
n 21	n 21
c.v. 8.5%	c.v. 14.9%
Fraction of Ra-E Recovered = 0.742	Fraction of Ra-F Recovered = 0.723

Table 2.8. Recovery of Ra-E and Ra-F from 15 ml blood samples spiked with the standardized Ra-D, Ra-E, Ra-F solution (426 pCi Ra-E/ml, 225 pCi Ra-F/ml), S.D. = standard deviation, $\bar{x}$ = sample mean, n = number of samples, c.v. = coefficient of variation.

Recovery of Ra-E in pCi/ml of Spike Solution		Recovery of Ra-F in pCi/ml of Spike Solution	
	131.469		27.780
	161.754		20.180
	211.128		35.657
	247.832		32.846
	252.091		31.018
	244.552		25.920
	210.012		29.390
	129.872		14.843
	148.852		28.000
	230.943		24.514
	269.433		81.823
S.D.	51.528	S.D.	17.504
$\bar{x}$	203.449	$\bar{x}$	31.996
n	11	n	11
c.v.	25.3%	c.v.	54.7%
Fraction of Ra-E Recovered = 0.477		Fraction of Ra-F Recovered = 0.142	

variation, and the fractional recovery of Ra-E and Ra-F are presented. Gotchy (1968) reported mean recoveries of Ra-E and Ra-F to be 0.620 and 0.889 respectively as compared to 0.477 and 0.142 in the present study. The recovery experiment was not repeated and little emphasis was subsequently placed on the blood data because only a small number of blood samples were obtained from the experimental subjects.

III. Determination of Sample Activity

A) Determination of Ra-E Activity

The activity of Ra-E in each sample was determined by one of two low-background beta particle detectors. The two instruments were functionally similar except that one instrument⁽¹⁾ required the operator to manually change samples under the two sample detectors while the other instrument⁽²⁾ automatically changed samples by means of a sequential sample changing mechanism. The low-background count rate for each instrument was attained by operation of the detectors within a two inch lead brick shield and by the utilization of an anticoincidence circuit which would nullify a signal from the sample detector upon receipt of a simultaneously-occurring signal in the guard detector. Both detectors were gas-flow Geiger-Mueller tubes requiring a gas mixture of 98.5 percent helium and 1.5 percent propane. The 0.7 mg/cm^2 doubly-gold-coated-mylar window in the sample detector permitted the entry of beta particles into the sensitive volume of the detector. Beta particles of 61 keV and 15 keV maximum energy were produced from Ra-D plated onto the nickel disks. Approximately 13 percent of the Ra-D, in the undigested sample, attached to the nickel disk (Blanchard, 1966). To obtain a measure of the Ra-E beta particles, 1.15 MeV maximum energy, as distinguished from the other beta particles produced, each sample was covered with a 6.7 mg/cm^2 aluminum absorber. Thus only the more energetic beta particles from Ra-E as opposed to Ra-D could penetrate the absorber and enter the sample detector. The calibration procedure for each instrument is presented in parts I and II of Appendix B.

(1) Sharp Low Beta Counter.

(2) Beckman Low Beta II.

B) Determinations of Ra-F Activity

The activity of Ra-F plated onto nickel disks was determined using an alpha spectrometry system and a gas flow proportional counter. The alpha spectrometry system was capable of counting three samples simultaneously. Each of the detection systems consisted of a 450 mm² by 100µm silicon surface-barrier detector⁽¹⁾, a preamplifier⁽²⁾, an amplifier⁽³⁾, a single channel analyzer⁽⁴⁾, a timer⁽⁵⁾, and a scaler⁽⁶⁾. The electronic components were housed in and powered by two NIM bins⁽⁷⁾ with a single power supply⁽⁷⁾, whereas the detector bias voltage was supplied by a pair of 67.5 volt batteries with a potentiometer to control the voltage. The three detectors were housed in a detector-sample holder represented in Appendix C. The sliding-drawer arrangement of the holder provides easy access to the samples and assures a reproducible geometry. To protect the silicon detectors from Ra-F contamination a 2µm thick rubber hydrochloride film⁽⁸⁾ was placed over the face of each detector by taping the film to the protective brass housing of the detector so as to avoid direct contact of the film with the delicate gold cathode on the face of the detector. The degradation of the Ra-F alpha-particle energy spectrum due to the rubber hydrochloride film was minimal as demonstrated by Ide (1967). Calibration of the spectrometry system, counting efficiencies, and typical background count rates are presented in part III of Appendix B.

A 2π gas flow proportional counter was utilized to count the Ra-F alpha particles produced from samples of greater activity than observed in the control hair samples or in the blood samples. The method of calibration, instrument counting efficiency, and typical background count rates are presented in part IV of Appendix B.

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- (1) Ortec Model #A055-450-100 silicon surface-barrier detector.
 - (2) Ortec Model #109A preamplifier.
 - (3) Ortec Model #485 amplifier or a Hamner Model #NA-11 amplifier.
 - (4) Ortec Model #406A single channel analyzer or a Hamner Model NC-11.
 - (5) Hamner Model #NT-15 timer-scaler.
 - (6) Ortec Model #703 dual register or a Hamner Model #NT-15 timer-scaler.
 - (7) Ortec #401A slave bin and a Hamner Model #NH84A bin (with power supply).
 - (8) Mitsuma Rubber Co., Ltd. (Japan) rubber hydrochloride obtained from Harold M. Ide of the Los Alamos Scientific Laboratory.

C) Counting Statistics

The low-level activity in most of the blood and whisker samples along with the large number of samples to be counted necessitated a statistical determination of the minimal counting time or the minimal number of accumulated counts necessary to maintain a maximum coefficient of variation of 20 percent. Counting a sample for sufficient time to achieve a counting accuracy smaller than 20 percent was not considered an efficient use of counting time especially when the large number of low activity samples were to be counted. General guidelines for the routine counting of samples were established using the following relationships presented in Lapp and Andrews (1964):

For a determination of the minimal number of counts to be accumulated,

$$N_t = \frac{R_t^2 + R_b^2}{V_s^2 R_s^2}$$

where N_t = Minimal number of counts to be accumulated

R_t = Count rate of the sample plus background

R_b = Count rate of the background

V_s = Coefficient of variation = 0.10 for calculation purposes only

R_s = Net count rate of the sample = sample plus background count rate - background count rate

For a determination of minimal counting time, T_t

$$T_t = \frac{R_t + R_b}{V_s^2 R_s^2}$$

where the symbols are as above.

To serve as a general counting policy a minimum of 500 counts was required for all Ra-E determinations and a minimum of 1000 minutes counting time was required for Ra-F determinations. The choice of these values was in part determined by preset count and preset time features of the instrumentation.

IV. Data Analysis

The magnitude and complexity of the accumulated data required all data analysis to be completed by a computer⁽¹⁾. Figure 2.10 presents a block diagram of the five computer programs utilized and the sequence of calculations performed. Four of the five programs are presented in Appendix D with a detailed description of the computational procedures involved. The remaining program is not unique to this study and is documented in the appendix. Only a brief description of the utility of each program and their interrelationships is presented below:

Program DPM calculates the Ra-D and Ra-F activity of each sample at the point in time representing the middle of sample collection. The input data consist of observed net activities for Ra-D and Ra-F, the chemical and counting efficiencies for both nuclides, the various dates and counting times necessary to correct for the decay of Ra-D, Ra-E and Ra-F between the time of sample collection and the time of activity determinations, the sample weights, a code to describe any problems encountered with the sample processing, and a code to identify each sample. Output from the program, printed on paper for visual inspection and punched on cards for entry into program Sort, consisted of the sample collection dates, expressed in day of the study, Ra-D and Ra-F specific activities expressed in disintegrations per minute (dpm) per gram, and a code for sample identification.

The computer card input to program Sort consisted of the Ra-D and Ra-F specific activities from program DPM, the mine-company determinations of working levels, and the TLD determinations of working levels. Associated with the data entries were the dates of each determination, and the codes to identify the type of determination for a miner or a control. Program Sort arranged the data according to the type of data, chronologically to starting dates and finally to the individual miner or control. All the data were then recorded on tape (1) for entry into program AV-PL.

(1) Control Data Corp., Model CDC 6400.

Figure 2.10. Block diagram of the computer program sequence used in the data analysis. CPM = counts per minute, DPM = disintegrations per minute, MINE CO. = mine-company determinations of average working levels, TLD = thermoluminescent-dosimetry determinations of average working levels.

Program AV-PL calculated 10-day, 30-day, and 90-day averages of all the working level determinations on tape (1). Program STAT37P was utilized to plot the mine-company determinations of average working levels against either the Ra-D or Ra-F levels observed in whisker tissue. The correlations between the TLD determinations of working levels and the mine-company determinations or the Ra-D or Ra-F levels in whiskers were likewise plotted. The resulting graphical representations were necessary to interpret the results of program REGN properly.

The same data cards used as input to program STAT37P were used as input to program REGN. The latter program established the degree of correlation between the variables plotted in program STAT37P and presented the necessary coefficients for power functions relating average working levels to the Ra-D or Ra-F content of the whiskers.

Chapter 3

RESULTS

I. Working Levels Determined by TLD and Mine-Company Samples

The TLD-air-sampler, bioassay, and mining-company determinations of exposure extended from September 9, 1968, to December 31, 1969, dependent upon the degree of participation of each miner and each control. For the data appearing in Appendix E and F, the time interval for each dosimetry period is presented as "day of study" day 1 corresponding to September 9, 1968, sequentially through day 479 corresponding to December 31, 1969. Appendix E presents the average working levels as determined by mine-company samples, and TLD samples. The mine-company values represent the average working levels determined by the mine-company ventilation engineers for the time period indicated under "day of study." The TLD sample presents estimates of the average working levels obtained from the monitoring systems provided to each miner by Colorado State University.

II. Specific Activities in Hair and Blood

Appendix F presents the Ra-D and Ra-F specific activity for whisker and blood samples in picocuries per gram of sample. For blood samples, only one day of study is presented, as indicated in the "stop" column. This single value represents the day of blood sample collection. The blood specific activity is expressed as picocuries per gram wet weight. The "day of study" for whisker samples indicates the time interval of whisker sample collection, and the specific activity is presented as picocuries per gram of dry weight. Each table in Appendix F presents dosimetric information for an individual miner or control subject.

III. Determination of Regression Equations Relating Working Levels and Specific Activities Observed in Whiskers

Regression equations in the form of power functions going through the origin, the zero-zero point, were selected as the general form of

the equations that best represented the data collected. The rationale behind the selection of the general form of the equations is presented in the discussion of the applicability of the regression equations derived by Gotchy.

Specific activities observed in whiskers and working levels determined by both the mine-company methods and by the TLD determinations were averaged over 30-day intervals and over the entire duration of the study, approximately 480 days. Negative values for individual net Ra-D and net Ra-F specific activities were considered erroneous values resulting from variations in chemical recoveries of Ra-F during chemical digestion of whisker samples. The negative values were entered as zeros into the calculation of both sets of averages. If the resulting average represented less than 40 percent of the total time interval for each average, the calculated average was not considered a valid representation of the measured parameter and was not used in the calculation of regression equations. Table 3.1 presents the regression equations derived from 30-day average specific activities and 30-day average determinations of working levels. A factor considered in the correlations of 30-day averages was the interval of time between inhalation of short-lived radon daughters and the uptake of Ra-D and Ra-F by whiskers. A 20-day time period between inhalation and uptake was utilized in the calculation of the regression equations presented in Table 3.1.

The regression equations derived from data averaged over the entire period of study are presented in Table 3.2. The restrictions enumerated above for the 30-day averages likewise apply to the formulation of averages covering the duration of the study. Figures 3.1 and 3.2 present the data points and regression lines for the correlation between mine-company determinations of working levels and Ra-D specific activities in whiskers from miners employed in mine company 1 and in mine company 2, respectively.

Table 3.1. Regression equations calculated from 30-day average specific activities observed in whisker samples collected from 40 miners and 30-day average working levels determined by TLD and mine-company monitoring methods.

Regression Equation	Correlation Coefficient	Sample Size	Data Utilized
<u>Mine company 1 determinations of working levels</u>			
$WL = 0.312D^{0.148}$	0.233	292	A11
$WL = 0.309F^{-0.011}$	-0.038	292	A11
<u>Mine company 2 determinations of working levels</u>			
$WL = 0.145D^{0.193}$	0.237	89	A11
$WL = 0.158F^{0.006}$	0.015	89	A11
<u>Mine companies 1 and 2 determinations of working levels</u>			
$WL = 0.216D^{0.147}$	0.209	381	A11
$WL = 0.270F^{0.008}$	0.025	381	A11
<u>TLD determinations of working levels in mine company 1</u>			
$WL = 0.102D^{0.083}$	0.051	137	A11
$WL = 0.092F^{-0.055}$	-0.094	137	A11
<u>TLD determinations of working levels in mine company 2</u>			
$WL = 0.196D^{-0.290}$	-0.312	28	A11
$WL = 0.294D^{0.155}$	0.400	28	A11
<u>TLD determinations of working levels in mine companies 1 and 2</u>			
$WL = 0.112D^{0.014}$	0.009	165	A11
$WL = 0.106F^{-0.025}$	-0.045	165	A11

Where: WL = 30-day average working level
 D = 30-day average Ra-D specific activity in whiskers
 F = 30-day average Ra-F specific activity in whiskers

Table 3.2. Regression equations calculated from the average specific activities observed in whisker samples during the entire study and the average working levels determined by TLD and mine-company monitoring methods over the same time interval

Regression Equation	Correlation Coefficient	Sample Size	Data Utilized
<u>Mine company 1 determinations of working levels</u>			
$WL = 0.314D^{0.292}$	0.340	17	All
$WL = 0.246D^{0.507}$	0.452	14	Specific activities below 7 pCi/g
$WL = 0.487F^{-0.011}$	-0.029	17	All
<u>Mine company 2 determinations of working levels</u>			
$WL = 0.099D^{0.464}$	0.587	17	All
$WL = 0.056D^{0.989}$	0.812	12	Specific activities below 9 pCi/g
$WL = 0.194F^{0.042}$	0.056	15	All
<u>Mine companies 1 and 2 determinations of working levels</u>			
$WL = 0.204D^{0.298}$	0.305	34	All
$WL = 0.094D^{0.975}$	0.588	24	Specific activities below 7 pCi/g
$WL = 0.363F^{-0.051}$	-0.071	32	All
<u>TLD determinations of working levels in mine company 1</u>			
$WL = 0.212D^{0.499}$	0.472	10	All
$WL = 0.465F^{-0.060}$	-0.128	11	All
<u>TLD determinations of working levels in mine company 2</u>			
--	--	0	None available
Mine company determinations of working levels (WL_{mine}) compared with TLD			
<u>determinations of working levels (WL_{TLD})</u>			
$WL_{\text{mine}} = 0.904(WL_{\text{TLD}})^{0.591}$	0.745	10	All
$WL_{\text{mine}} = 0.465(WL_{\text{TLD}}) + 0.355$	0.697	10	All
<u>Ra-D specific activities compared with Ra-F specific activities</u>			
$F = 5.669D^{-0.014}$	-0.009	32	All
$F = 0.186D + 6.891$	0.178	32	All

Where: WL = working levels averaged over the duration of the study
D = Ra-D specific activity averaged over the duration of the study
F = Ra-F specific activity averaged over the duration of the study

Figure 3.1. Relationship between 480-day average mine company 1 estimates of working levels and 480-day average Ra-D specific activities in whiskers.

Figure 3.2. Relationship between 480-day average mine company 2 estimates of working levels and 480-day average Ra-D specific activities in whiskers.

Chapter 4

DISCUSSION

I. Review of Objectives

The objective of the research presented in this report was to quantitatively compare and contrast three methods for the determination of exposure to uranium miners by short-lived radon daughters:

1. mine-company determinations of exposure through periodic air sampling and exposure-time estimation in specific work areas of the mine,
2. TLD determinations of exposure through individual-miner air sampling, and
3. bioassay determinations of exposure through the analysis of long-lived radon daughters in whiskers and blood.

The bioassay determinations were based on the work by Gotchy (1968). He established the relationship between tissue specific activity and mean working levels to which the miners in the Schwartzwalter Mine were exposed. Before his results could be used in the above comparisons a knowledge of the applicability of his regression equations to a different mining situation was necessary. Mining in the Schwartzwalter Mine near Golden, Colorado, was in a granitic schist formation and work was conducted exclusively with pneumatic equipment. In contrast, the uranium mines in the Grants, New Mexico, area were in a sandstone formation and utilized diesel equipment to varying degrees. The effect of such differences on the bioassay determinations was of concern because the limitations and applicability of Gotchy's equations were unknown. Once these factors were established a comparison of the three different methods was possible.

II. Bioassay Tissue Selection

Gotchy (1968) established correlations between average working levels in a mine atmosphere and Ra-D and Ra-F specific activities in both blood and whiskers. The limited number of blood samples collected and processed made a determination of the limitations and applicability

of Gotchy's regression equations for blood impractical, especially when one considers the high variability of the chemical recoveries observed from blood samples. Thus whisker samples were chosen in preference to blood samples for the establishment of a bioassay monitoring program.

III. Applicability of the Bioassay Regression Equations Derived by Gotchy

The regression equations relating Ra-D and Ra-F specific activities in whiskers to average working levels was established by Gotchy (1968) using 16-month averages from each of 18 miners. The wide range of working levels reported, 0.23 WL to 5.77 WL, correlated well, $r = 0.879$ to $r = 0.916$, with average specific activities ranging from 0.60 pCi per g to 1.03 pCi per g. Average working levels were determined by radon film badges and periodic air samples. In contrast, the data collected in the New Mexico mines were more limited in range and volume. The narrow range of average working levels, 0.041 WL to 1.770 WL, and the narrow range of 30-day average specific activities in whiskers, 0.534 pCi per g to 3.420 pCi per g, resulted in poorer correlation coefficients than were reported by Gotchy. The selection of a general form for the regression equations was difficult because the limited range of the New Mexico data created only small differences in correlation coefficients between different forms of the equations. Regression equations in the form of power functions going through the origin, the zero-zero point, were selected for the following reasons:

1. Gotchy found that power functions were the best representation of the Schwartzwalter Mine data. The representation of the New Mexico data by power functions was not significantly improved by the use of either linear or exponential relationships.
2. The object of an examination of the correlations between average working levels and Ra-D or Ra-F specific activities for the New Mexico data was to determine the applicability of Gotchy's regression equations to a new and expanded mining situation and not to derive new relationships.

3. Theoretically, the regression equations should pass through the zero-zero point because an exposure to zero working levels should result in a zero net specific activity in whiskers. The net specific activities in whiskers were calculated by subtracting the average background specific activity observed in the whiskers of control subjects from the measured specific activities in miners' whiskers.

A) Regression Equation Based on 30-Day Averages

Regression equations based on the 30-day average specific activities observed in whisker samples collected from 40 miners and on the 30-day average working levels determined by TLD and mine-company monitoring methods were presented in Table 3.1. The regression equations and correlation coefficients account for a 20-day delay between the inhalation of radon daughters and the appearance of Ra-D and Ra-F in whiskers of clippable length, e.g., average mine-company determinations of working levels for day 1 through day 30 were correlated with average specific activities for day 20 through day 50. The correlations for 30-day averages were poor in comparison with the correlations reported by Gotchy (1968) but the relationship presented in Table 3.1 were only 30-day averages as opposed to the 16-month averages of Gotchy. Thus correlations were established for the New Mexico data based on 480-day averages, a close approximation to the 16 month averages.

1) The time delay between uptake and occurrence of Ra-D and Ra-F in hair - was indicated by the data collected in the experiment described below:

Each of two goats were orally spiked with approximately 20 mCi of Ra-F. Prior to spiking, the hair was completely shaved with electric clippers from the left side of each animal and the area mapped into eight equal portions using a felt marking pen. The numbers one through eight were assigned at random to each square. At the time intervals presented below, hair clippings were collected from the designated areas.

<u>Day Post Spiking</u>	<u>Areas Shaved</u>
0	all areas
10	1&2;
20	1&2; 3&4
31	3&4; 5&6
41	5&6; 7&8
51	7&8

In the shaving schedule each sample consisted of hair from a pair of numbered areas, e.g., shaved areas one and two represent the combined hair clippings from areas one and two. With the exception of day zero, approximately 10 days after the initial shaving the same area was shaved a second time. Thus the second shaving of areas five and six would represent hair growth during the time from day 30 to day 40. Table 4.1 presents the specific activities in picocuries Ra-F per gram of goat hair as a function of the number of days post spiking, the area of the animal shaved, and the goat shaved. Figures 4.1 and 4.2 illustrate the Ra-F specific activities as a function of the number of days post spiking for the following situations: curve A, the specific activity of 0-day, 10-day, 20-day, 30-day and 40-day growths of hair, and curve B, the successive 10 day growths of hair.

Both animals demonstrated maximum specific activities 20-days post-oral administration of Ra-F. Thus in an attempt to establish the highest correlation between inhalation of radon daughters and the appearance of Ra-D and Ra-F in the whiskers of uranium miners, a 20-day delay between the two events was utilized.

B) Regression Equations Based on 480-Day Averages

Regression equations calculated from the average specific activities observed in whisker samples during the entire period of study and the average working levels determined by TLD and mine-company monitoring methods over the same time interval were presented in Table 3.2. The resulting correlation coefficients, when compared to the correlation coefficients based on 30-day averages, Table 3.1, are in all cases higher, a phenomenon which may well result from the loss of variability when individual measurements are averaged over a large time interval. The 480-day correlations may be compared to the relationships found by Gotchy (1968) and presented below:

Regression Equation	Correlation Coefficient	Sample Size
$WL = 0.433D^{0.713}$	0.879	17
$WL = 0.311F^{0.633}$	0.921	17

Table 4.1. Specific activities of Ra-F in goat hair (picocuries per gram of hair) presented as a function of the number of days post-spiking, the numbered area shared on each animal, and the number of each animal.

Day Post Spiking	Area Shaved	Goat Number	pCi Ra-F per g hair
0	all	1	1.136
10	1&2	1	1459.240
20	1&2	1	4670.025
20	3&4	1	4201.710
31	3&4	1	679.676
31	5&6	1	2292.100
41	5&6	1	162.933
41	7&8	1	913.180
51	7&8	1	104.528
0	all	2	23.428
10	1&2	2	219.324
20	1&2	2	911.288
20	3&4	2	770.200
31	3&4	2	59.081
31	5&6	2	340.595
41	5&6	2	39.208
41	7&8	2	229.033
51	7&8	2	9.307

Figure 4.1. Ra-F specific activity in picocuries per gram of hair from Goat I as a function of the number of days post-spiking.

Figure 4.2. Ra-F specific activity in picocuries per gram of hair from Goat II as a function of the number of days post-spiking.

In general the correlation coefficients presented in Table 3.2 are lower than those found by Gotchy. The New Mexico data does, however, add significantly to the work presented by Gotchy:

1) Differences between regression equations for different mine companies - are evident by the lack of improvement of the correlation coefficients for the averages from both mine companies considered jointly as opposed to separate consideration. The chemical determinations of specific activities for both mine companies were performed on a random sample-selection basis using identical chemical procedures. Thus the lack of improvement must be a result of either the differences in mine-company determinations of working levels or the differences in mine-company ventilation rates.

2) The operation of the TLD system - was not as anticipated. A comparison of the sample sizes presented in Table 3.2 demonstrates the lack of data collected from the TLD determinations of working levels in comparison to the bioassay determinations or the mine-company determinations. The successful operation of the TLD system was impaired by problems encountered with the air sampling portion of the TLD system. Water and grains of dirt were continually corroding and binding moving parts in the diaphragm air pump, the valves of the air pump often failed to close efficiently, and mud frequently caused clogging of the air inlet of the filter head unit. The severe battering of normal mining operations and user tampering with individual TLD systems caused additional problems with the system, all of which were not apparent in the laboratory tests conducted on the units and reported in the materials and methods section of this report. The TLD data from mine company 1 was sufficiently complete to serve as a comparator for mine-company determinations of working levels, as is discussed below, but the TLD data from mine company 2 was not sufficiently complete for any of their participating miners to provide such a basis of comparison. Recommendations for future development of a TLD system usable in the uranium mine industry are presented in the section on refinements of monitoring techniques.

3) Systematic air sampling methods - The data points represented in Figures 3.1 and 3.2 have been designated by the use of circles and dots. On both figures the points represented by dots

correspond to high Ra-D specific activities and low average working levels. Regression equations were calculated and presented in Table 3.2 for the data represented by the circles in both figures. For both mine companies 1 and 2 the regression equations for the data represented by circles demonstrated higher correlation coefficients than when all the data from a given mine company was used to calculate the regression equations. In addition, the regression equation for the TLD determinations of working levels in mine company 1 and the Ra-D specific activities is very similar to the regression equation for the data represented by circles in mine company 1. If the TLD determinations of working levels are in fact superior to the mine-company determinations then the data points represented by dots on both figures may reflect systematic errors in the air-sampling methods used by each mine company. Such errors could easily result from air sampling in fresh air streams as opposed to the actual working location of the miner.

4) Correlations of Ra-F specific activities and working levels - were effectively nonexistent for all the cases presented in Table 3.2. In contrast Gotchy (1968) reported a correlation of 0.916 for Ra-F specific activities and working levels. Variations in chemical recoveries of Ra-F from the New Mexico samples may have accounted for the lack of correlation and the elimination of Ra-F in whiskers as a bioassay determination of exposure for the New Mexico miners.

5) Correlations of Ra-D specific activities and working levels - for the New Mexico study group were not as high as the correlations reported by Gotchy (1968), 0.340 and 0.587 as opposed to Gotchy's reported 0.879. The regression equations derived for the New Mexico data were considerably different from Gotchy's equation. The geological differences between the two locations, sandstone in the New Mexico mines as opposed to granite in the Colorado mine, may have produced sufficiently different particle size distributions in the two areas to produce the observed difference between regression equations.

IV. Sources of Ra-D

Bioassay systems for uranium miners utilize the measurement of specific nuclides in biological samples to determine the exposure to uranium miners from the decay of inhaled short-lived radon daughters. Ideally the nuclide chosen for measurement has only one source, the decay of short-lived radon daughters, but such is not the case with Ra-D. Holtzman (1970) estimated that in bones of uranium miners, approximately 43 percent of the Ra-D originated from the decay of the short-lived radon daughters deposited in the lung, 27 percent was from the inhalation of ore dust and preformed Ra-D in the atmosphere, i.e., Ra-D formed in the mine atmosphere before inhalation by a miner, 30 percent came from the decay of radon dissolved in body fluids, and 1 percent from normal environmental contributions. The first three sources of Ra-D are applicable to the Ra-D in the whisker bioassay system reported in this publication whereas the latter source of Ra-D was removed through subtraction of the observed background levels of Ra-D in whisker clippings of the controls from the specific activities observed in miners' whiskers.

A) Calculation of the Percentage of Each Ra-D Source

The following sources of Ra-D were considered for the purpose of calculating the contribution of each source to the total intake of Ra-D by uranium miners:

1. Ra-D derived from the inhalation and subsequent decay of short-lived radon daughters,
2. Ra-D inhaled as preformed Ra-D present in the mine atmosphere⁽¹⁾, and
3. Ra-D resulting from the decay of radon gas dissolved in the body fluids of miners.

The different states of disequilibrium between Ra-A, Ra-B, Ra-C, Ra-C', and Ra-D present in a mine atmosphere may be approximated by the degree

(1) The Ra-D atoms are probably attached to dust particles or to condensation nuclei in the mine atmosphere, but may exist as free atoms.

of disequilibrium present in air at different time periods after initial conditions of only radon gas present in the air (Raabe, 1970). Thus air referred to as 30-minute old air represents the state of disequilibrium present after the decay for 30 minutes of radon gas initially free from its daughter products. A well-ventilated mine is represented by 30-minute old air whereas a poorly-ventilated mine is represented by 20-hour old air. The number of Ra-D atoms per working level-liter is calculated for any age atmosphere as follows:

The number of atoms of the short-lived radon daughters per 100 pCi radon was calculated using the Bateman equations for each time period considered. Multiplication of the number of atoms of each of the short-lived radon daughters by the alpha particle energy available in decay of each atom through Ra-C' resulted in the total alpha energy available from each short-lived daughter. Subsequent division of 1.3×10^5 MeV per working level-liter by the summation of those energies produced a factor that when multiplied by 100 pCi radon per liter resulted in the number of picocuries of radon necessary to produce one working level in air of the age being considered. The number of atoms of the short-lived radon daughters and the number of Ra-D atoms produced from that quantity of radon necessary to produce one working level in the specified time period was calculated by the Bateman equations. The decay of each short-lived radon daughter to atoms of Ra-D allows one to equate the calculated number of atoms of each short-lived radon daughter to atoms of Ra-D from each source. For example:

60-MINUTE OLD AIR

Number of Atoms per 100 pCi Rn per Liter			Alpha Energy Available in Decay of Each Atom Through Ra-C' (MeV)		Total Alpha Energy Per 100 pCi Rn per Liter (MeV)
Ra-A	970	x	13.68	=	1.325×10^4
Ra-B	6503	x	7.68	=	4.994×10^4
Ra-C	3114	x	7.68	=	2.392×10^4
Ra-C'	~0	x	7.68	=	0
total				=	8.711×10^4

$$\frac{1.3 \times 10^5 \text{ MeV/WL-1}}{8.711 \times 10^4 \text{ MeV/l}} = \frac{1.492}{\text{WL}}$$

$$\left(\frac{1.492}{\text{WL}}\right) \left(\frac{100 \text{ pCi Rn}}{1}\right) = \frac{1.49 \times 10^2}{\text{WL-1}} \text{ pCi Rn}$$

	Number of Atoms per WL-1	Number of Ra-D Atoms per WL-1	Total Number of Ra-D atoms from the short- lived daughters
Ra-A	1.448×10^3	1.448×10^3	
Ra-B	9.705×10^3	9.705×10^3	
Ra-C	4.678×10^3	4.678×10^3	1.583×10^4
Ra-D	3.955×10^3	3.955×10^3	

The total number of atoms of Ra-D from the short-lived radon daughters, and the number of atoms of Ra-D preformed in the air before inhalation were each converted to atoms of Ra-D per working level month by assuming the inhalation of 15 liters of air per minute for the 170 working hours per month yielding a total of 1.5×10^5 liters and by assuming a 40 percent retention of the radon daughters. The number of atoms of Ra-D originating from radon per working level month was calculated using a body volume of 70 liters and a distribution coefficient of 0.9 for the average concentration at equilibrium of radon in body tissue (Nussbaum, 1957). The effective body volume is then 63 liters, (70 liters x .9). The radon calculations were based on a build-up period, when exposure begins, equal to the expiration period at the termination of exposure. The total number of picocuries of radon present in the effective body volume was then multiplied by 2.24×10^4 daughter atoms, i.e., ultimate Ra-D atoms, produced per picocurie of radon in the 170 working hours per month. The total number of atoms of Ra-D per working level month from all three sources was then calculated and each source expressed as a fraction of the total. An example for 60-minute old air is presented below:

Sources of Ra-D	Atoms of Ra-D per Liter	Liters of Air Inhaled Per 170 Working Hours	Retention Coefficient	Atoms Ra-D Per WLM	Percentage
Inhaled short- lived daughters	1.583×10^4	$\times 1.530 \times 10^5$	$\times .4 =$	9.670×10^8	(68.1%)
Inhaled pre- formed Ra-D	3.955×10^3	$\times 1.530 \times 10^5$	$\times .4 =$	2.420×10^8	(17.0%)
Radon dissolved in body fluids	$\left(\frac{149 \text{ pCi Rn}}{1} \right) (63 \text{ l}) \left(\frac{2.244 \times 10^4 \text{ daughters}}{\text{pCi-WLM}} \right) = 2.109 \times 10^8$				(14.9%)
TOTAL					1.420×10^9

Table 4.2 presents the number of atoms of Ra-D per working level month for each of the three sources considered and the percentage of the total number of Ra-D atoms for air of the following ages: 3 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, 10 hours, and 20 hours. The percentage contribution from each source of Ra-D as a function of age of the air is illustrated on triangular coordinates in Figure 4.2. For air of age equal to 3 minutes or less radon is effectively the only source of Ra-D because the short-lived radon daughters have not had sufficient time to form. Between 30 minutes and 1 hour the short-lived radon daughters are the principle sources of Ra-D whereas in atmospheres older than approximately 2 hours the preformed Ra-D in the atmosphere is the main source of Ra-D.

B) Leakage of Old Air into Ventilation Air Streams

In actual mining situations the ventilation air rarely will be 100 percent of a given age. Mine companies intentionally block off mined-out areas of a mine to prevent the influx of radon and radon daughters from these areas into the air used for ventilation. Thus in Figure 4.3 two different ventilation conditions have been presented to simulate the leakage of old air into air used for mine ventilation. The curve in the middle of Figure 4.1 represents a mixture of 5 percent

Table 4.2. Ra-D Atoms per Working Level Month as a Function of the Age of Mine Air

Source of Ra-D Atoms	3 Minute	15 Minute	30 Minute	1 Hour	2 Hour
Inhaled short-lived radon daughters	6.626×10^8 (22.4%)	8.458×10^8 (58.2%)	9.240×10^8 (69.7%)	9.670×10^8 (68.1%)	9.761×10^8 (50.2%)
Inhaled preformed Ra-D atoms	0 (00.0%)	3.550×10^6 (00.2%)	6.070×10^7 (4.6%)	2.420×10^8 (17.0%)	8.146×10^8 (41.9%)
Radon	1.946×10^9 (74.6%)	5.956×10^8 (41.2%)	3.411×10^8 (25.7%)	2.109×10^8 (14.9%)	1.557×10^8 (8.0%)
Total	2.609×10^9	1.445×10^9	1.326×10^9	1.420×10^9	1.946×10^9
	95.0% 3 Minute 05.0% 20 Hour	95.0% 15 Minute 05.0% 20 Hour	95.0% 30 Minute 05.0% 20 Hour	95.0% 1 Hour 05.0% 20 Hour	95.0% 2 Hour 05.0% 20 Hour
Inhaled short-lived radon daughters	6.780×10^8 (20.6%)	8.032×10^8 (38.5%)	9.263×10^8 (44.7%)	9.672×10^8 (44.7%)	9.758×10^8 (36.6%)
Inhaled preformed Ra-D atoms	7.650×10^8 (23.2%)	7.650×10^8 (36.7%)	8.227×10^8 (39.7%)	9.949×10^8 (46.0%)	1.538×10^9 (57.8%)
Radon	1.849×10^9 (56.2%)	5.182×10^8 (24.8%)	3.241×10^8 (15.6%)	2.005×10^8 (09.3%)	1.480×10^8 (05.5%)
Total	3.292×10^9	2.086×10^9	2.073×10^9	2.163×10^9	2.662×10^9

Table 4.2. - (Continued)

Source of Ra-D Atoms	10 Hour	20 Hour		
Inhaled short-lived radon daughters	9.887×10^8 (11.5%)	9.706×10^8 (06.0%)		
Inhaled preformed Ra-D atoms	7.573×10^9 (88.4%)	1.530×10^{10} (94.0%)		
Radon	1.542×10^8 (01.8%)	2.244×10^6 (0.10%)		
Total	8.716×10^9	1.627×10^{10}		
	80.0% 3 Minute 20.0% 20 Hour	80.0% 15 Minute 20.0% 20 Hour	80.0% 30 Minute 20.0% 20 Hour	80.0% 1 Hour 20.0% 20 Hour
Inhaled short-lived radon daughters	7.242×10^8 (13.6%)	8.708×10^8 (17.4%)	1.516×10^6 (10.8%)	9.677×10^8 (22.0%)
Inhaled preformed Ra-D atoms	3.060×10^9 (57.3%)	3.663×10^9 (73.1%)	3.065×10^{10} (94.5%)	3.254×10^9 (74.1%)
Radon	1.557×10^9 (29.2%)	4.769×10^8 (9.5%)	2.774×10^8 (00.9%)	1.692×10^8 (03.9%)
Total	5.343×10^9	5.011×10^9	3.244×10^{10}	4.391×10^9

Figure 4.3. Percentage of Ra-D taken into the body of a uranium miner from the decay of inhaled short-lived radon daughters, from inhaled preformed Ra-D, and from the decay of radon dissolved in body fluids.

20-hour air with 95 percent air of ages ranging from 3 minutes to 10 hours. Such a set of situations may well occur in actual mining situations. The curve on the right represents the mixture of 20 percent 20-hour air with 80 percent air of ages 3 minutes to 10 hours. This curve has been included to illustrate an extreme situation of leaky bulkheads and leaky air doors in a poorly ventilated mine. Other curves similar to the family of curves represented in Figure 4.1 may be constructed to meet specific ventilation conditions. The shift in curves resulting from the mixture of old air with air of a given age is apparent in Figure 4.3. Miners working in atmospheres comprised of such mixtures as opposed to air of only one age will receive an increased percentage of preformed Ra-D in proportion to increased percentages of old air in the mixture. Decreased percentages of Ra-D from inhaled short-lived radon daughters and decreased percentages of Ra-D from radon accompany the increased percentage of old air mixed with the ventilation air.

1) Measurement of the sources of Ra-D - The number of atoms of Ra-D per working level month was measured under actual mining conditions for the sources of Ra-D referred to above (Eisenbud and Wrenn, 1969). Each of the six determinations was converted to the number of Ra-D atoms per working level month and is presented in Table 4.3. The percentage contribution of each source of Ra-D to the total amount of Ra-D is indicated by a data point on Figure 4.3. The determinations are in good agreement with the theoretical curves presented in the figure. Five of the six determinations represent ventilation air of less than 30 minutes residence time in the mine and the remaining determination represents ventilation air of slightly more than 30 minutes residence time. Similarly most of the samples represent ventilation air with less than 15% contribution of air with a long residence time, e.g., 20 hours. Even though the data was collected from a mine located in the Colorado Plateau, similar measurements would be expected in the mines participating in the New Mexico study.

C) Importance of Ra-D Sources to a Ra-D Bioassay System

The objective of a Ra-D bioassay system is to utilize the specific activity of Ra-D observed in a biological tissue to determine exposure to a uranium miner. The Ra-D atoms resulting from the

Table 4.3. Determinations of the number of Ra-D atoms per working level month under actual mining conditions

Sources of Ra-D Atoms	Number of Ra-D Atoms Per Working Level Month		
Inhaled short-lived radon daughters	9.611×10^8 (29.9%)	9.690×10^8 (72.8%)	9.613×10^8 (41.3%)
Inhaled preformed Ra-D	1.551×10^9 (48.2%)	5.098×10^7 (3.8%)	9.159×10^8 (39.3%)
Radon	7.069×10^8 (22.0%)	3.117×10^8 (23.4%)	4.526×10^8 (19.4%)
Total	3.219×10^9	1.332×10^9	2.330×10^9
Inhaled short-lived radon daughters	9.612×10^8 (27.4%)	9.565×10^8 (34.4%)	9.620×10^8 (32.5%)
Inhaled preformed Ra-D	2.053×10^9 (58.6%)	1.331×10^9 (47.8%)	1.677×10^9 (56.7%)
Radon	4.890×10^8 (14.0%)	4.948×10^8 (17.8%)	3.174×10^8 (10.7%)
Total	3.503×10^9	2.782×10^9	2.956×10^9

inhalation and subsequent decay of short-lived radon daughters are the most important in this respect because of the association of lung cancer with the decay of the short-lived daughters in the respiratory system. In addition to Blanchard's report (1969) of the relation between Ra-D from the decay of short-lived radon daughters and Ra-D from other sources, the effect of old air leaking into a mine ventilation air stream has been shown in Figure 4.2 to be an importance source of Ra-D atoms for underground uranium miners.

Under the conditions of a well-ventilated mine, the Ra-D bioassay system in whiskers would function at maximum efficiency. The maximum percentage of Ra-D associated with the inhalation and subsequent decay of short-lived radon daughters occurs for air between the ages of 15 minutes and 1 hour. Raabe (1970) states that in a well-ventilated mine the radon daughters in the air are in a state of disequilibrium equivalent to 30-minute old air. If one assumes a range of disequilibrium states equivalent to air between the ages of 15 minutes and 1 hour and also assumes less than a 10 percent contribution of old-age air, the percentage of Ra-D associate with the inhalation and decay of short-lived radon daughters as illustrated in Figure 4.3 is in the approximate range of 30 percent to 70 percent. Such a range of percentages should include the majority of miners in the mine company especially when mine companies utilizing the Ra-D in whiskers bioassay system realize that a decrease in contribution of old air to the ventilation air will result in a lower Ra-D intake for each miner and therefore a lower working-level determination. The extensive area of most underground mining operations and the limited use of air recirculation filters in poorly-ventilated areas of a mine limit the number of men exposed to air of less than 15 minutes age. Exposure to atmospheres older than 1 hour would likewise be limited because higher working levels occur in old air as opposed to air of age less than 1 hour. Thus to comply with Federal exposure limits uranium-mine companies attempt to employ most of their miners in mine atmospheres less than 1-hour old.

1) Exposure to air of age less than 15 minutes or greater than 1 hour - Figure 4.4 presents a plot of the number of Ra-D atoms per working level month as a function of the age of the atmosphere in

Figure 4.4. Intake of Ra-D atoms by a uranium miner as a function of the age of a mine atmosphere.

hours. The three curves in the figure present data from Table 4.2 for the sources of Ra-D referred to above. The conditions of a well-ventilated mine are indicated in the figure for air between the ages of 15 minutes and 1 hour. On either side of the designated region the curve representing preformed Ra-D and Ra-D from radon increases whereas the curve for Ra-D from the short-lived daughters remains relatively constant. The overall effect is an increase in the total amount of Ra-D on either side of the 15 minute to 1 hour region for a constant working-level exposure. Thus a bioassay system based on Ra-D would produce an overestimation of the exposure incurred in air less than 15-minutes old or greater than 1 hour old. The degree of overestimation for an atmosphere of age "t" may be approximated by the following ratio:

$$\frac{\text{Total Ra-D intake for "t"-minute old air}}{\text{Total Ra-D intake for 30-minute old air}}$$

Table 4.4 presents a list of overestimation factors for different age atmospheres. Ra-D bioassay systems could overestimate a miner's exposure by a factor of two if the miner worked exclusively in 3-minute old ventilation air or in ventilation air recently filtered to remove all radon daughters. In contrast exposures may be overestimated by as much as a factor of 12 if the miner works in very old air, e.g., 20-hour old air.

Table 4.4. Maximum overestimation factors for a Ra-D bioassay system as a function of the age of mine air

<u>Age of Air</u>	<u>Overestimation Factor</u>
3 minutes	2.0
15 minutes	1.1
1 hour	1.1
2 hours	1.5
10 hours	6.6
20 hours	12.3

The original data reported by Eisenbud and Wrenn (1969) was converted to atoms of Ra-D per working level month for presentation in Table 4.3.

Higher Ra-D concentrations than those observed for mine air between the ages of 15 minutes to 1 hour would occur immediately after blasting

because dust particles with Ra-D attached are mixed with ventilation air by the blasting procedure. For the mines in the New Mexico study this source of Ra-D was of minimal concern because all blasting occurred immediately before the termination of the swing shift, 4 pm to 12 pm. The mine was not re-entered until the following morning. Thus the continual ventilation during the night would clear the mine of Ra-D on dust particles resulting from blasting. Similar blasting schedules in other mines would have the same effect.

V. Refinements of Monitoring Techniques

A) TLD Personal Monitoring System

The limited number of 480-day average TLD determinations of working levels, as illustrated by the sample sizes presented in Table 3.2, indicates the need for further development of a TLD system before it can be used successfully in a large scale monitoring program. Based on the experience gained with the TLD system used in this study, the following areas of development are suggested:

1. The air pump should be an integral part of a miner's lamp battery rather than a separate unit from the lamp battery. The air pump should be wired in such a manner that when a miner turns his lamp on the air pump is automatically turned on. Such an arrangement would obligate each miner to transport the monitoring system throughout his working area in a mine because a miner's light is usually the only source of illumination underground.
2. The air pump must be completely sealed to prevent water and particulate matter from corroding and binding the moving parts of the pump.
3. The filter-head unit should be designed as an integral part of the miner's lamp. The air inlet of the filter-head should be shielded from direct impaction of mud or other particulate matter.
4. The entire unit should be as compact and light as possible.
5. The final testing procedure should involve miner usage under actual mining conditions. Laboratory testing usually

underestimates the severe and abusive treatment encountered by equipment in the mining operations.

B) Ra-D in Whisker Bioassay System

The detection of alpha particles from Ra-F in whisker samples required a wet-chemical digestion and plating procedure to prevent alpha-particle absorption in biological media. The study presented in this report has indicated the limited value of Ra-F in whiskers as a bioassay system for uranium miners, thus the wet-chemical digestion of whiskers would not be necessary in an applied Ra-D bioassay system using determinations of Ra-E in equilibrium with Ra-D.

The following recommendations are presented for further development of a Ra-D bioassay system prior to the application of the bioassay system to all the miners in the uranium mine industry:

1. The percentage Ra-D from the inhalation and decay of the short-lived radon daughters, from the inhalation of preformed Ra-D in the atmosphere, and from radon dissolved in body fluids should be determined for typical areas of mining in each of the mine companies prior to using the bioassay system. If appreciable differences are suspected between mines operated by a given mine company, then determinations of Ra-D sources should be made for individual mines operated by the mine company. The number of atoms of Ra-D from the first source could be obtained from alpha spectrometric determinations of the number of short-lived radon daughters filtered from a given volume of air. Large volume air sampling filters would allow determinations of the number of Ra-D atoms from the first and second sources. Subtraction of the number of atoms of the first source from the total of the first and second sources would provide knowledge of the number of atoms of preformed Ra-D in a given volume of mine air. Measurements of the radon concentrations would allow one to determine the number of atoms of Ra-D from radon per unit volume of mine air. Conversion of the above data to number of Ra-D atoms per working level month, as was illustrated in the discussion of the sources of Ra-D, and calculations of the percentage of the total number

of Ra-D atoms for each source would allow one to determine if the mines intending to use the bioassay system were within the limits of a well-ventilated mine as indicated in Figure 4.4.

2. A new Ra-E counting procedure should be developed to detect the Ra-E beta particles directly from miners' whiskers, thereby eliminating loss of Ra-E atoms during a chemical digestion procedure. A counting instrument employing an automatic sample changing mechanism would save considerable time and allow samples to be counted 24 hours a day.
3. The establishment of good correlations between average working levels and Ra-D specific activities observed in whiskers from uranium miners is of considerable importance to the practical application of a Ra-D bioassay system. Daily monitoring of the working levels where a miner is employed should provide the necessary average working levels to establish the correlations. The monitoring may be accomplished by either the Kuznetz method employed by mine ventilation personnel or by a newly designed TLD system as described above.
4. Application of the Ra-D in whiskers bioassay system to all personnel employed underground in the uranium-mine industry would require strict adherence by all the underground employees to a set whisker collection schedule. Weekly collections of whiskers assure that the employees shave at least once a week and avoids claims that a few days' collection of whisker clippings represents an entire month's accumulation of whiskers. The weekly collections must be submitted during vacation periods as well as during work periods, otherwise regions of high or low Ra-D specific activity appearing in whiskers of clippable length may not be included in the whisker samples pooled for a quarter of a year.

The initial costs of setting up the Ra-D in whiskers bioassay system as a monitoring system for a specific mine company would be higher than the subsequent routine monitoring costs. The higher initial costs would be caused by the analysis of the percentages of Ra-D from

the different sources specified in the above discussion, the establishment of regression equations for different mining environments, and by administrative costs of starting a new monitoring program. Subsequent costs of routine exposure determinations would be much lower than incurred in this study because of the elimination of the wet-chemical digestion procedures and possible substitution of a more efficient Ra-E counting system.

VI. Summary and Conclusions

Quantitative comparisons and contrasts were established between the following methods for the determination of exposure to miners from the short-lived radon daughters in a uranium mine atmosphere:

1. mine-company area monitoring and exposure-time estimation,
2. personal TLD monitoring, and
3. bioassay of Ra-D and Ra-F specific activities in whiskers and blood of uranium miners.

The following results and conclusions are based on the above determinations of exposure over a period of 480 days for study groups of 40 uranium miners and 10 controls, both groups from the Grants, New Mexico area:

A) Personal TLD Monitoring System

Laboratory tests of the personal TLD monitoring system developed at Colorado State University indicated that the system would provide high-quality personal monitoring of uranium miners and would provide exposure data for a comparison of each of the other two monitoring systems. The TLD monitoring system did not prove to be a usable system under practical mine application because of the difficulties encountered with the air-pump component of the system and because of the user problems encountered with the TLD system. Implementation of the suggested refinements of the system should provide a personal monitoring method for general use in the uranium-mine industry but the ultimate expense of each TLD system may prove to be prohibitive.

B) Bioassay Monitoring System

The feasibility of a blood or whisker bioassay system was presented by Gotchy (1968) and provided the basis of an investigation

of the utility of such systems. The collection of monthly blood samples was found to be nearly impossible whereas the submission of weekly whisker samples was easily controlled. The highest correlations between the physical determinations of working levels, by either the TLD system or by the mine-company monitoring, and the Ra-D or Ra-F specific activities observed in whiskers were observed for data averaged over the 480-day study period. The Ra-D specific activities provided much better correlations with average working levels than did the Ra-F specific activities but the correlations appeared dependent on mining location and/or quality of mine ventilation. A different regression equation was reported by Gotchy (1968) for his study area in the Colorado front range than was observed in the Grants, New Mexico mines. Differences were observed likewise between the regression equations from the two mine companies participating in this study.

The correlations between Ra-D specific activities in whiskers and current exposures, i.e., average working levels, was low in comparison to the correlations presented by Gotchy (1968) and low in comparison to bioassay correlations presented in the literature for the determination of cumulative exposures. If a bioassay system is to be used to monitor the exposure of uranium miners, further development is needed on the detection of Ra-E beta particles from undigested whisker samples and on the factors affecting the correlations between Ra-D specific activities and average working levels, e.g., more frequent determinations of working levels, and determination of the sources of Ra-D.

1) Sources of Ra-D - Of the total Ra-D input to a uranium miner the percentage of Ra-D associated with the decay of inhaled short-lived radon daughters is dependent on the residence time of the ventilation air in a mine and dependent on the leakage of air from nonventilated areas into the ventilation air stream. The variation in residence times of the air breathed by a miner will have an effect on any uranium-miner bioassay system based on the incidence of long-lived radon daughters in any biological samples. For miners working in well-ventilated portions of a mine with little leakage of nonventilation air into the ventilation air streams this effect will be minimal, but for poorly ventilated areas an overestimation of miners' exposure will result from uncorrected bioassay determinations.

C) The Mine-Company Area Monitoring and Exposure-Time Estimation

The correlations of Ra-D specific activities and mine-company determinations of working levels in both mine companies appeared to be grouped into categories representing low and high mine-company determinations of working levels. Correlations of available TLD determinations of working levels with Ra-D specific activities agreed with the correlations of the low-working-level group data and Ra-D specific activities. Both observations indicate that selective air sampling methods may be used by both mine companies in the determination of working levels and that more rigid controls may be necessary for consistently accurate determinations of working levels by mine-company personnel.

D) Conclusions

The TLD personal-monitoring system and the bioassay system based on Ra-D specific activities were both developed to provide personal monitoring of uranium miners as opposed to the area monitoring utilized by the mine companies. At the current stage of development however, neither personal-monitoring system can be recommended for use in the uranium-mine industry. The mine-company area monitoring and exposure-time estimation provides exposure determinations suitable for continued use in the industry but investigation of more rigid controls of the method may be warranted to prevent possible selective air-sampling procedures.

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BIBLIOGRAPHY

- Archer, V. E., S. C. Black, W. C. Dixon, and G. Saccomanno. 1969. Urine and tissue content of ^{210}Pb and ^{210}Po in uranium miners, p. 553-574. In Symposium on Diagnostic and Treatment of Deposited Radionuclides. U.S. At. Energy Comm. No. CONF560521.
- Black, Stuart C., V. E. Archer, W. C. Dixon, and G. Saccomanno. 1968. Correlation of radiation exposure and lead-210 in uranium miners. Health Physics 14:81-93.
- Blanchard, Richard L. 1966. Rapid determination of lead-210 and polonium-210 in environmental samples by deposition on nickel. Anal. Chem. 38, 189-192.
- Blanchard, Richard L. 1969. Radon-222 daughter concentrations in uranium mine atmospheres. Nature 223:287-289.
- Cohen, Norman, and G. Parry Howells. 1969. A brief review of ^{210}Pb metabolism, p. I-18-I-97. In New York Health and Safety Laboratory. 1969. Fallout program. Quarterly summary report, Sept. 1 - Dec. 1, 1968. New York Health and Safety Laboratory, U.S. At. Energy Comm. No. HASL-204, (Also published as NYO-3086-8: III-1-III-18) 1-15.
- Cohen, Norman and T. J. Kneip. 1969. A method for the analysis of ^{210}Pb in the urine of uranium miners. Health Physics 17: 125-130.
- Eisenbud, Merril, et al., 1969. In vivo measurements of lead-210 as an indicator of cumulative radon daughter exposure in uranium miners. Health Physics 16:637-646.
- Eisenbud, Merril, and McDonald E. Wrenn. 1969. Radioactivity studies progress report. Contract at (30-1) 3086. Gov't Doc. No. NYO-3086-8. (Part III).
- Evans, R. D. 1969. Engineer's guide to the elementary behavior of radon daughters. Health Physics 17(No. 2):229-252.
- Fink, Robert M. 1950. Biological studies with polonium, radium and plutonium. McGraw-Hill Book Co., Inc., New York. 411 p.
- Gotchy, Reginald L. 1968. A survey of bioassays for uranium miners. U.S. At. Energy Comm. Special Report No. COO-1500-10. 156 p. (See also Health Physics 17:199-218).
- Hearings. 1969. Radiation Standards for Uranium Mining, hearings before the Subcommittee on Research Development, and Radiation of the Joint Committee on At. Energy, 91st Congress of the United States. U.S. Government Printing Office, Washington, D.C. 414 p.

BIBLIOGRAPHY - (Continued)

- Hewlett-Packard. 1969. Program library for calculator model 9100B. Hewlett-Packard Corporation, Loveland, Colorado.
- Holtzman, Richard B. 1970. Sources of ^{210}Pb in uranium miners. Health Physics 18:105-112.
- Ide, Harold M. 1967. Evaluation of a rubber hydrochloride film for radiometric purposes. Los Alamos Scientific Report No. H5MR67-1. 5 p.
- Jaworowski, Z. 1969. Radioactive lead in the environment and in the human body. Int. At. Energy Agency, Vienna, At. Energy Rev. 7(No. 1)1-45.
- Kusnetz, Howard L. 1956. Radon daughters in mine atmospheres - a field method for determining concentration. Amer. Ind. Hyg. Ass. 17:85-88.
- Lapp, Ralph E., and Howard L. Andrews. 1964. Nuclear Radiation Physics. Prentice-Hall, Inc., Englewood Cliffs. 413 p.
- Martz, Dowell E., Dan F. Holleman, David E. McCurdy, and Keith J. Schiager. 1969. Analysis of atmospheric concentrations of Ra-A, Ra-B, and Ra-C by alpha spectroscopy. Health Physics 17:131-138.
- McCurdy, David E. 1969. Thermoluminescent dosimetry for personal monitoring of uranium miners. U.S. At. Energy Comm. Special Report No. COO-1500-16. 168 p. (Also see Health Physics 17:415-422).
- Nussbaum, E. 1957. Radon solubility in body tissues and in fatty acid (Thesis), University of Rochester (USAEC Research and Development Report UR-503), Rochester. In Raabe, Otto G. 1970. Concerning the relationship of lead-210 and inhalation exposure to radon-222. (A letter to the editor). Health Physics 18:733-734.
- Raabe, Otto G. 1970. Concerning the relationship of lead-210 and inhalation exposure to radon-222. (A letter to the editor). Health Physics 18:733-734.
- Schiager, Keith J. 1969. Radon progeny inhalation exposures to uranium miners, progress report No. 1 for the period: June, 1968 - March, 1969. National Institute of Health Contract No. PH-43-68-1326, Dept. of Health, Education, and Welfare. 26 p.
- Steel, Robert G. and James H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill. 451 p.
- Widdowson, Elsie and J.W.T. Dickerson. 1964. Chemical composition of the body. In Comar, C.L. and Felix Bronner (eds.). 1964. Mineral metabolism an advanced treatise. Vol. 11 (Part A) 2-207.

APPENDIX A

PARTICIPANTS' PERSONAL HISTORIES AND INSTRUCTIONS

Colorado State University, Ft. Collins, Colorado 80521

PARTICIPANT'S PERSONAL DATA FORM

Name: _____ Social Security No. _____
 Last First Middle

Miner: _____ non-miner _____ relation to miner _____

Birthdate: _____ Height: _____ Weight: _____
 Month Day Year

Race: Caucasian _____ Negro _____ American Indian _____ Other _____

Health History: Have you ever been hospitalized or treated for any lung disease? _____
 Do you have hay fever or other types of allergies? _____
 _____ (If yes to either of the above, give details on back). Date of last chest X-ray? _____
 Where was it taken? _____
 Reason: _____

Smoking History:	Cigarettes per day				Cigars			Pipe
While age	1-20	21-40	41-60	61 +	1-3	4-6	7+	Regularly
Under 15								
15-24								
25-34								
35-44								
45-54								
55-64								
65-								

Employment History: Please include all periods from most recent back to start of full-time work.

Dates:	From	To	Employer and Location	Type of Work

Research Participation: I, the undersigned, agree to participate in the study of radiation exposures to uranium miners conducted by Colorado State University (CSU) as follows:

1. I agree to wear and use the personal air samplers according to the instructions given by CSU personnel.
2. I agree to collect and turn in whisker samples regularly according to the instructions given by CSU personnel.

Figure A.1. Participant's Personal Data Form.

PARTICIPANT'S PERSONAL DATA FORM - (Continued)

3. If I decide not to participate in the study for 12 months, I will return the electric razor provided for whisker sample collection.
4. I hereby authorize my employer to provide my radiation exposure records to CSU for use only in this research study.
5. I am/am not willing to have a blood sample taken once a month during the study period.

Date: _____ Signed: _____

Address: _____

Figure A.1. Participant's Personal Data Form - (Continued)

URANIUM MINERS RADIATION EXPOSURE STUDY

General Purpose and History

Since 1965 Colorado State University has been conducting basic research on the exposure of uranium miners to radioactive materials. The research is now being supported by both the Atomic Energy Commission and the U.S. Public Health Service. The purpose of this research is to analyze and subsequently prevent harmful radiation exposures to miners which may possibly lead to severe future illness and loss of work. It is only through your cooperation that this research may be continued to successful completion.

Instructions to Participating Miners

1. Collection of Whiskers
 - a. Clean the razor once a week, or more often if necessary, by pushing the button on the side to open the "flip-top" shaving head. Brush the whisker shavings into the envelope provided.
 - b. Seal the envelope and label as follows:
 - 1) The date whisker collection began.
 - 2) The date whisker collection ended.
 - 3) Your name.
 - c. Turn in the sealed envelopes once a week to the mine office and pick up a new envelope for next week's whisker shavings.
 - d. It is not necessary to shave every day, but it is important that all whisker shavings be collected each week.
 - e. If you go on vacation, or are not working underground for other reasons, for four days or more of any week, mark the envelope "OFF WORK." It is important that weekly whisker samples still be collected. Turn in all samples to the mine office when you return to work.
 - f. If you transfer to another uranium mine that is included in the sampling program, please continue to turn in weekly whisker samples.
 - g. If you quit working in uranium mines, you may keep the razor IF:
 - 1) You write to the address below to inform us of your home address, and
 - 2) You continue to send weekly whisker samples. (We will send the necessary mailing envelopes directly to you).
2. Collection of Blood Samples (for those who volunteer)
 - a. Once a month please report to the appointed nurse or physician to have a small blood sample taken.
 - b. You will be paid directly by check from Colorado State University at the rate of \$2.50 per blood sample. Payment will normally be made after every three (3) or four (4) samples collected.

Figure A.2. Instructions issued to participating miners

3. Use and Care of Personal Air Sampling Monitors

- a. Each miner participating in the research program will be issued a numbered air pump to be used for the entire research period. If the pump should stop notify the proper mining official. He will then issue a replacement pump.
- b. The sampler should be turned on at the start of your work shift and turned off at the end of each shift. The sampler is turned on by inserting the grey plug attached to the white string into the plug socket on the top of the pump. The pump is turned off by removing the plug.
Note: The pump operates on a cycle, on for approximately two (2) seconds and off for approximately eight (8) seconds.
- c. Before work, the pump and filter holder on the hat are connected to the plastic tube attached to the lamp cord by twisting the metal connector clockwise. Be sure that the connectors are secure.
- d. At the end of the shift the pump and hat units must be disconnected from the plastic tube so that your lamp battery can be charged. The pump and hat are detached by twisting the connectors counterclockwise. After five (5) shifts of use (usually on weekends), the air pump is to be turned into the proper mine official so that its battery can be charged.
- e. The metal filter holder on the hat will be exchanged every two (2) weeks. The filter holder is attached to the metal connector on the end of the tube mounted on the hat. The filter holder is then secured in the metal clip. If the filter holder happens to "pop" out of the clip, the hose should keep it from getting lost until you are able to insert it into the clip again.
- f. You will be notified in advance of the date for exchanging the filter holder. It should be left on the hat during the entire use period between exchanges.
- g. DO NOT OPEN THE FILTER HOLDER FOR ANY REASON. It contains several recording materials that must not be disturbed.
- h. Report any loss, damage, or malfunction of air pumps, filter holder, or connecting tube to the proper mine officials as soon as possible.

THANKS

Your interest and cooperation are very much appreciated. We hope through your assistance our research will reduce the health risks to all uranium miners.

Department of Radiology and Radiation Biology
COLORADO STATE UNIVERSITY
Fort Collins, Colorado 80521

Figure A.2. Instructions issued to participating miners - (Continued)

URANIUM MINERS RADIATION EXPOSURE STUDY

General Purpose and History

Since 1965 Colorado State University has been conducting the basic research on the exposure of uranium miners to radioactive materials. The research is now being supported by both the Atomic Energy Commission and the U.S. Public Health Service. The purpose of this research is to analyze and subsequently prevent harmful radiation exposures to miners which may possibly lead to severe future illness and loss of work. It is only through your cooperation that this research may be continued to successful completion.

Instructions for Mine Management

1. Air Sampling Pumps
 - a. The pumps operate on a cyclic mode, two (2) seconds on and eight (8) seconds off. The cycle permits the pumps to run a week (40 hours) without recharging its battery.
 - b. On each sampler is a stroke counter marked "minutes." The pumps have been calibrated to relate the volume of air sampled to the number of strokes registered. The reading on the stroke counter should be recorded at least weekly, but preferably daily. The reading can be reported by the miner at the beginning or end of the day. The stroke count readings should be entered on the record sheets for the actual dates on which the readings are obtained. If a pump should stop or not start, a replacement pump should be issued. The pump number and the stroke count should be recorded on the date of issue.
 - c. The pump battery must be charged for at least 14 hours after each 40 hours of operation; a weekend charge is even more desirable. The battery cannot be damaged by overcharging. The batteries are charged by inserting the plug of the charger into the plug receptacle on top of the pump. A switch on the charger enables the user to check each plug to see if the battery is being charged. The voltmeter will read between 5.8V and 6.0V when the batteries have been recharged an hour or more. Do not be alarmed if a reading of 8.9V occurs. A discharged battery will initially draw more current giving a greater reading but the reading should go to 6V after a period of charging. If it does not, the battery may have a bad cell.
 - d. The charger has a 1/4 amp fuse as a safety precaution. If the fuse should blow, disconnect the pump and insert another fuse. If the fuse flows without any pump attached, then the charger has internal troubles. However, if this fuse does not blow, then a pump battery may be shorting.

Figure A.3. Instructions issued to mine management

A process of elimination can be used to find the faulty pump and permit the other pumps to be charged.

- e. The pump number and stroke counter number, as well as the filter holder number, are to be recorded on the air sampler data sheet. The pump number and filter holder number need only be entered once for each two week period, except if an exchange is made. The stroke counter number is recorded daily or at least weekly. This is very important. Without the stroke count, the average WL exposure cannot be calculated.

2. Filter Holders

- a. Each filter holder is stamped with a number. When issued, the filter holder number should be recorded on the miner's record sheet. The filter holder is attached to the metal connector on the end of the hose mounted on the hat. The filter holder is then secured in the metal clip. Filter holders will be exchanged by mail every two weeks. The used filter holders and record sheets are to be placed in the self-addressed folder which comes with the new filter holders and sent to Colorado State University.
- b. If a filter holder becomes lost or damaged, issue a replacement and make a note of the event on the record sheet.

3. Data Sheets

- a. The information requested on each miner's data sheet is essential to the success of the research. The data sheet includes the WL and work time records used in the standard method of calculating exposures. It also includes spaces for recording the pump numbers, stroke count readings, filter holder numbers, hours of respirator use (if applicable) and dates whisker samples are turned in.
- b. Please enter all of the requested items and send the completed data sheets with each mailing of filter holders and whisker samples.
- c. A notebook is provided for keeping the data sheets and instructions. A sample data sheet is included to illustrate the correct recording procedure.

4. Monitoring Records

The results obtained from the monitoring program will be supplied to each participating mine.

5. Mail Exchange of Materials

- a. Exchange filter holders, envelopes for whisker collection, additional data sheets and pre-stamped mailing packets will be sent to each participating mine every two (2) weeks.
- b. After the filter holders have been exchanged, return the used filter holders, whisker samples and data sheets in the mailing packet. All packets will be metered as first class mail, so please feel free to include a note about any problems or questions.

6. Problems or Questions

- a. If time permits, please write to us about any difficulties. Names and address are on the following page. If the difficulties are such that the monitoring program will be interrupted if not corrected promptly, please call collect.
- b. Problems concerning air sampling pumps, battery chargers or filter holders should be referred to David McCurdy.
- c. Problems concerning whisker (or blood) sampling should be referred to Noel Savignac.

Return Visits

Someone from Colorado State University (attached list) will visit the mine periodically (perhaps every 4 to 6 weeks) to insure that the research is continuing as planned and to discuss any problems which may arise.

THANKS

Your interest and cooperation are very much appreciated. We hope that through your assistance our research will reduce the health risks to all uranium miners.

PROJECT ADDRESS

Uranium Miners Radiation Exposure Study
Department of Radiology and Radiation Biology
Biophysical Sciences Building
Colorado State University
Fort Collins, Colorado 80521

URANIUM MINERS RADIATION EXPOSURE STUDY

General Purpose and History

Since 1965 Colorado State University has been conducting basic research on the exposure of uranium miners to radioactive materials. The research is now being supported by both the Atomic Energy Commission and the U.S. Public Health Service. The purpose of this research is to analyze and subsequently prevent harmful radiation exposure to miners which may possibly lead to severe future illness and loss of work. It is only through your cooperation that this research may be continued to successful completion.

Instructions to Participating Non-Miners

1. Collection of Whiskers
 - a. Clean the razor once a week, or more often if necessary, by pushing the button on the side to open the "flip-top" shaving head. Brush the whisker shavings into the small envelope provided.
 - b. Seal the small envelope carefully and completely to prevent loss of whisker shavings in the mail and label as follows:
 - 1) The date whisker collection began.
 - 2) The date whisker collection ended.
 - 3) Your name.
 - c. Every two weeks, place the small envelopes in the mailing envelope and mail to Colorado State University. Additional envelopes will be supplied regularly.
 - d. It is not necessary to shave every day, but it is important that all whisker shavings be collected each week.
 - e. If you go on vacation or leave Grants, New Mexico, for more than four days, mark the small envelope "on vacation." It is important that weekly whisker samples still be collected and sent to Colorado State University during these time periods.
2. Collection of Blood Samples (for those who volunteer)
 - a. Instructions will be sent as soon as the necessary arrangements have been made with a local physician.
 - b. You will be paid directly by check from Colorado State University at the rate of \$2.50 per blood sample. Payment will normally be made after every three (3) or four (4) samples collected.

Figure A.4. Instructions issued to non-miners

THANKS

Your interest and cooperation are very much appreciated. We hope that through your assistance our research will reduce the health risks to all uranium miners.

Uranium Miners Radiation Exposure Study
Department of Radiology and Radiation Biology
Biophysical Sciences Building
COLORADO STATE UNIVERSITY
Fort Collins, Colorado 80521

Figure A.4. - (Continued)

Table A.1. Summary of the personal histories of the miners and controls participating in the study.

	Number of Miners in Mine Section				Number of Controls
	A	B	C	D	
<hr/>					
Total Number of Years of Smoking					
10 or less	2	3	1	2	4
11-15	2	2	1	2	2
16-20	2	4	1	3	0
21-25	1	2	3	1	4
26-30	2	0	1	1	1
Greater than 30	1	0	3	1	4
<hr/>					
Individual's Age at Beginning of Study					
30 or less	1	1	0	0	4
31-35	2	4	1	4	2
36-40	2	5	5	4	4
41-45	4	0	1	1	1
46-50	1	1	3	1	4
<hr/>					
Total Number of Years Spent in Mining					
0					15
1-5	1	0	1	2	
6-10	1	4	0	3	
11-15	4	1	6	2	
16-20	1	4	2	2	
21-25	3	1	0	1	
Greater than 25	0	1	1	0	
<hr/>					

APPENDIX B
INSTRUMENT CALIBRATION PROCEDURES

APPENDIX B

INSTRUMENT CALIBRATION PROCEDURES

I. Sharp Low Beta Counter

A calibrated beta reference source for Ra-E⁽¹⁾ containing 0.0229 $\mu\text{Ci} \pm 10\%$ in 1967 was used to determine the counting efficiency of Sharp Low Beta counter. Ra-D, Ra-E, Ra-F was deposited on a one-inch diameter by 0.010 inch copper planchet and covered with a 7.15 mg/cm^2 aluminum foil of mass attenuation coefficient equal to $1.45 \times 10^{-2} \text{ cm}^2/\text{mg}$. The transmission factor was calculated as follows:

$$T_{\text{std}} = e^{-(\mu/\rho)(x\rho)}$$

T_{std} = Transmission factor for the Ra-E standard

$$T_{\text{std}} = e^{-(1.45 \times 10^{-2})(7.15)}$$

μ/ρ = Mass attenuation coefficient in cm^2/mg

$$T_{\text{std}} = 0.902$$

$x\rho$ = Density thickness in mg/cm^2

Each sample to be counted was covered with a 6.7 mg/cm^2 aluminum foil filter. In a similar manner the transmission factor for Ra-E beta particles penetrating through the filter was calculated as follows:

$$T_f = e^{-(1.45 \times 10^{-2})(6.7)}$$

T_f = Transmission factor for the filtered sample

$$T_f = 0.907$$

If:

E_o = The observed counting efficiency of Ra-E beta particles calculated by:

$$E_o = \frac{\text{Observed cpm from the Ra-E standard} - \text{cpm background}}{\text{dpm of the Ra-E standard}}$$

(1) New England nuclear source, Model #453

then the actual counting efficiency could be calculated by the following:

$$E_a = \frac{E_o}{T_{std}}$$

E_a = Actual counting efficiency of Ra-E beta particles.

Likewise if:

Q_o = Observed sample activity with the aluminum filter - background activity,

Q_a = Sample activity without the filter - background activity,

then:

$$Q_a = \frac{Q_o}{T_f}$$

Thus:

$$\frac{Q_a}{E_a} = \frac{Q_o}{E_o} \frac{T_{std}}{T_f} = 0.994 \frac{Q_o}{E_o}$$

Conclusion. One may approximate the actual sample activity to within 0.6 percent by dividing the observed sample activity using the aluminum absorber by the observed counting efficiency determined with the Ra-E standard

Backscatter is a function of both the energy of the beta particles and the atomic number, Z , of the material backing the source. In the above calibration procedure beta particles of similar energy distributions were being detected from the standard and from the samples. In addition the ratio of Z for the copper planchet in the standard to the Z of the nickel disks upon which the samples were plated is $29/28 = 1.036$. Thus the effects of backscatter are considered negligible in the above calibration procedure.

The average efficiency of the Sharp Low Beta Counter for the detection of Ra-E beta particles is 0.245. A typical background count rate was 0.300 cpm.

II. Beckman Low Beta II

As the Ra-E standard available used to calibrate the Sharp Low Beta Counter could not be counted easily in the Beckman Low Beta II due to geometry problems, a series of 10, Ra-D, Ra-E, Ra-F sources were air dried on nickel disks. Each sample was counted in the Sharp Low Beta Counter of known counting efficiency and then counted in the Beckman Low Beta II. The counting efficiency for the Beckman Low Beta II was then calculated as follows:

$$E_b = \frac{R_b}{R_s} E_s$$

E_b = Counting efficiency of the Beckman Low Beta II

R_b = Average count rate of the 10 samples as determined in the Beckman Low Beta II - average background activity.

$$E_b = 0.405$$

R_s = Average count rate of the 10 samples as determined in the Sharp Low Beta - average background activity.

E_s = Average counting efficiency of the two sample detectors in the Sharp Low Beta.

Conclusion. The average counting efficiency of the Beckman Low Beta II is 0.405. A typical background count rate was 0.900 cpm.

III. Alpha Single-Channel Spectrometry System

To serve as a source for calibration of the alpha spectrometry system, Ra-F was plated onto a 13/16 inch diameter nickel disk and

calibrated against a ^{238}U standard⁽¹⁾ in a two π gas flow proportional counter⁽²⁾ equipped with an electronic scaler to avoid the resolving time problems of a mechanical register. Calibration of the source activity resulted in 70400 dpm on January 10, 1969. Los Alamos Scientific Laboratory determined that the source should have produced 66210 dpm on that date. The difference in calibration procedures represents 5.9 percent. The Ra-F on nickel source was used to determine the counting efficiency of the silicon surface barrier detectors at various time periods throughout the study. Counting efficiencies for each of the detectors ranged from 0.239 to 0.290 with background count rates in the range of 0.009 cpm to 0.018 cpm depending on how frequently the protective rubber hydrochloride film was changed (see section on materials and methods).

IV. Gas Flow Proportional Counter

The determination of counting efficiency at various time intervals for the 2π gas flow proportional counter⁽³⁾ was obtained using a ^{239}Pu source⁽⁴⁾. Counting efficiencies ranged from 0.459 to 0.515 and the background count rates ranged from 0.084 to 0.134 cpm.

-
- (1) Tracerlab ^{238}U source serial #A-196 calibrated on 7/24/61 to produce 1164 alpha per minute in a 2π geometry.
 - (2) Nuclear Associates 2π gas flow proportional counter model #J4-138 with an Ortec Model #446 high voltage power supply, an Ortec Model #109PC preamplifier, an Ortec Model #485 amplifier, an Ortec Model #484 scaler, an Ortec Model #225 timer, and an Ortec Model #401A NIM with power supply.
 - (3) Nuclear Measurements PC2 gas flow proportional counter.
 - (4) U.S. Atomic Energy Commission, Rocky Flats Plant, ^{239}Pu source #SS-96 (10701 dpm on 8/23/67).

APPENDIX C

DETECTOR - SAMPLE HOLDER

The following set of schematic drawings represent a detector-sample holder designed to accommodate four Ortec Model #A055-450-100 silicon surface-barrier detectors and four samples with maximum dimensions of $7/8$ inch diameter by $1/16$ inch thick.

Figure C.1. Detector-sample holder, front view of assembled unit.

Figure C.2. Detector-sample holder, top piece.

Figure C.3. Detector-sample holder, drawer piece.

Figure C.4. Detector-sample holder, bottom piece.

Figure C.5. Detector-sample holder, one of two identical drawer spacers.

APPENDIX D

COMPUTER PROGRAMS USED IN THE ANALYSIS OF DATA

APPENDIX D

COMPUTER PROGRAMS USED IN THE ANALYSIS OF DATA

Program DPM

The derivation of equations for the Ra-D, Ra-E, Ra-F decay chain were presented by Gotchy (1968) in Appendix A. The results are summarized below:

Parent nuclide = Ra-D

First daughter = Ra-E

Second daughter = Ra-F

A_1^0 = Activity of Ra-D initially

A_1^t = Activity of Ra-D at time t

A_2^0 = Activity of Ra-E initially

A_2^t = Activity of Ra-E at time t

A_3^0 = Activity of Ra-F initially

A_3^t = Activity of Ra-F at time t

λ_1 = Decay constant of Ra-D

λ_2 = Decay constant of Ra-E

λ_3 = Decay constant of Ra-F

The activity of the parent nuclide (Ra-D) at time $t = 0$ is

$$A_1^0 = A_1^t e^{\lambda_1 t} \quad \text{Equation (1)}$$

The activity of the first daughter (Ra-E) at time $t = 0$ is

$$A_2^0 = A_2^t e^{\lambda_2 t} - \frac{\lambda_2 A_1^0 (e^{(\lambda_2 - \lambda_1)t} - 1)}{\lambda_2 - \lambda_1} \quad \text{Equation (2)}$$

The activity of the second daughter (Ra-F) at time $t = 0$ is

$$A_3^0 = A_3^t e^{\lambda_3 t} - \frac{\lambda_3 \lambda_2 A_1^0 (e^{(\lambda_3 - \lambda_1)t} - 1)}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)} + \frac{\lambda_3 \lambda_2 A_1^0 (e^{(\lambda_3 - \lambda_2)t} - 1)}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_2)} - \frac{\lambda_3 A_2^0 (e^{(\lambda_3 - \lambda_2)t} - 1)}{\lambda_3 - \lambda_2}$$

Equation (3)

The derivation of an equation for the correction of Ra-E decay between the end of sample plating and the end of sample counting was presented in Appendix A of Gotchy (1968). For purposes of calculations in program DPM, his equation has been separated into two components:

$$A_2^c = \frac{N \lambda_2}{1 - e^{-\lambda_2 t_c}}$$

Equation (4)

where A_2^c = Ra-E activity at the beginning of sample counting

N = Total number of counts accumulated during sample counting time

λ_2 = Decay constant of Ra-E

t_c = Sample counting time,

To correct for Ra-E decay between plating and the beginning of counting:

$$A_2^p = A_2^c e^{\lambda_2 t_p}$$

Equation (5)

where A_2^p = Ra-E activity at the end of sample plating

t_p = Elapsed time between the end of plating and the beginning of counting.

The sequence of calculations for Ra-D and Ra-F activities in each sample at the midpoint in time of sample collection is presented in

Fig. D.1.

Figure D.1. Chronological sequence of events for processing each sample, (A) = beginning of sample counting, (B) = end of sample plating, (C) = midpoint of sample collection.

The initial calculation in the program corrects for the decay of Ra-E during beta counting. To express the result in terms of dpm per g at point (A) on the time scale of Fig. D.1 the counting efficiency of Ra-E, the fractional recovery of Ra-E, and the sample weight were incorporated into the denominator of Eq. (4). The correction for Ra-E decay between the end of sample plating, point (B) on Fig. D.1, and the beginning of sample counting was calculated by Eq. (5). Because all of the samples were at least 30 days old before sample plating, the Ra-E activity was equal to the Ra-D activity at the beginning of sample plating. Due to the short plating time, compared to the Ra-E half-life, equilibrium is assumed to prevail likewise at point (B), the end of sample plating. The activity of Ra-D at the midpoint of sample collection point (C) in Fig. D.1 was then calculated by Eq. (1).

Ra-F in contrast to Ra-E has a half-life far in excess of the counting time. Thus no corrections for Ra-F decay during alpha counting were necessary. Ra-E was considered the parent nuclide on the nickel disk and Ra-F the first daughter because less than 13

percent of the Ra-D in the original sample was plated on the nickel disks and a small time interval, in comparison with the half-life of Ra-F, had elapsed between plating and Ra-F counting. The Ra-F activity at point (B) of Fig. D.1 was then calculated through the use of Eq. (2). The Ra-F counting efficiency, the fractional recovery of Ra-F, and the sample weight were entered into the denominator of Eq. (2) to obtain dpm Ra-F per g. As the Ra-D activity at the midpoint of sample collection had already been calculated, the Ra-F activity at point (C) was determined by Eq. (3). The final term of Eq. (3) was deleted from the calculations because the correction for ingrowth of Ra-E originally present in the sample is negligible and because the original Ra-E activity was not known.

On occasion the calculated Ra-D and Ra-F activities at the midpoint of sample collection were negative. These values were attributed to a loss of Ra-F, during chemical processing, in excess of the percentage loss determined in the recovery experiments and reported in the material and methods section. All of the negative values were reset to zero for subsequent working level determinations but a special sample code was instituted to designate the alteration of the calculated value.

In the second section of program DPM working levels were calculated from Ra-D and Ra-F activities. The output from program DPM consisted of a paper printout of all input data and all the calculated values. One could obtain the calculated Ra-D and Ra-F values for each sample or obtain the calculated working levels on computer card output. A listing of program DPM is provided as Table D.1.

Program Sort

Program Sort accepted as input any combination of the calculated Ra-D and Ra-F activities, calculated working levels from program DPM, the mine-company determinations of working levels, and the TLD working-level determinations. The data were first sorted according to the type of data, secondly, according to the starting dates of each value, and finally according to the miners' or controls' initials. A listing of Program Sort is provided in Table D.2.

Program AV-PL

The first portion of Program AV-PL calculated 10-day, 30-day, or 90-day averages of Ra-D and Ra-F specific activities or any of the working level determinations. The averages were calculated by dividing the sum of the daily determinations by the total number of days for which determinations existed. For example, the average Ra-D determinations for the second 30-day period for miner number 41 was calculated as follows:

Day of Study Start Stop	Number of Days Used to Calculate the Average	dpm Ra-D per gram
8 32	3	0.595
40 53	14	1.450
54 81	7	1.532
Day 60 Σ Day 30	$\frac{(3)(0.595) + (14)(1.450) + 7(1.532)}{46} = 0.998$	
Number of Days		

A listing of program AV-PL is provided in Table D.3.

Program REGN

Program REGN was a least-squares exponential curve fit program formulated for use on an electronic programmable calculator (Hewlett Packard, 1969) and converted for use in a computer. The general reference for the program is STEEL and TORRIE, 1960.

Table D.1. A listing of Program DPM

JLIMITS,CM77777,T50,PR99,PU999.1V501TF,
RFL(45000)
FTN.
RFL(100)
RFL(77777)
LGO.

PROGRAM DPM (INPUT,OUTPUT,TAPES=INPUT,TAPE6=OUTPUT,PUNCH,TAPE4)

DO NOT SUBMIT MORE THAN 499 DATA CARDS PER RUN

DIMENSION IKODE(500)
DIMENSION ITEST(500)
REAL LD,LF,LEM,M(500,29),LE,LEH
REAL MM(500)
DIMENSION C(500)
DATA MASK/00000000770000000000B/
DATA MASS/00000000030000000000B/

C(I)= SAMPLE CODE= FIRST AND LAST INITIALS,BATCH NUMBER,SAMPLE TYPE,
B= BLOOD SAMPLE, C= CONTROL SAMPLE, M= MINERS WHISKER SAMPLE
M(I,1)= MONTH OF STARTING COLLECTION DATE
M(I,2)= DAY OF STARTING COLLECTION DATE
M(I,3)= YEAR OF STARTING COLLECTION DATE
M(I,4)= MONTH OF TERMINATING COLLECTION DATE
M(I,5)= DAY OF TERMINATING COLLECTION DATE
M(I,6)= YEAR OF TERMINATING COLLECTION DATE
M(I,7)= ELAPSED TIME BETWEEN END OF PLATING AND END OF
COUNTING = BETA TIME IN HOURS
M(I,8)= COUNTING EFFICIENCY BETA = CTEB
M(I,9)= CHEMICAL EFFICIENCY BETA = CMEB
M(I,10)= SAMPLE WEIGHT
M(I,11)= OBSERVED COUNTS PER MINUTES BETA = DB CPMB
M(I,12)= COUNTING EFFICIENCY ALPHA = CTEA
M(I,13)= CHEMICAL EFFICIENCY ALPHA = CMEA
M(I,14)= OBSERVED COUNTS PER MINUTE ALPHA = DB CPMA
M(I,15)= BETA COUNTING TIME IN MINUTES = BCT
M(I,16)=TIME BETWEEN THE MIDPOINT OF SAMPLE COLLECTION AND THE END OF
SAMPLE PLATING IN DAYS
M(I,17)= DPM RA(D)
M(I,18)= DPM RA(F)
M(I,19)= STARTING COLLECTION DATE EXPRESSED AS DAY OF STUDY
M(I,20)= STOPPING COLLECTION DATE EXPRESSED AS DAY OF STUDY
WLD,WLF,CWLD,CWLF HAVE DIFFERENT MEANINGS WHEN USED IN REGRESSION

```

C
C      M(I,21)= WORKING LEVELS RA(D) = WLD
C      M(I,22)= WORKING LEVELS RA(F) = WLF
C      M(I,23)= WORKING LEVELS RA(F) CORRECTED FOR NONOCCUPATIONAL BACKGROUND
C      LEVEL OF RA(F) = CWLF
C      M(I,24)= WORKING LEVELS RA(D) CORRECTED FOR NONOCCUPATIONAL BACKGROUND
C      LEVEL OF RA(D) = CWLD
C      M(I,25)= MONTH SAMPLE PLATING FINISHED
C      M(I,26)= DAY SAMPLE PLATING FINISHED
C      M(I,27)= YEAR SAMPLE PLATING FINISHED
C      M(I,28)= TIME BETWEEN THE END OF SAMPLE COLLECTION AND THE BEGINNING OF
C      SAMPLE COLLECTION = SAMPLE COLLECTION INTERVAL = SCI
C      M(I,29)= ELAPSED TIME IN DAYS BETWEEN THE END OF RA(E) COUNTING AND THE
C      END OF RA(F) COUNTING =TBBA

```

```

C      ZERO OUT CORE

```

```

C      N6 = 6
C      AV1 = AV2 = 0
C      A = B = CC = 0
C      DPMF = DPMD = 0.0
C      WLD=CWLD=0.0
C      WLF=CWLF=0.0
C      TDPMD = TDPMF = ICONT = 0
C      LD=LF=LEM=LE=LEH=0

```

```

C      DO 1000 KK=1,11500
C      M(KK) = 0
1000 CONTINUE

```

```

C      DO 1100 KK=1,500
C      IKODE(KK) = 0
C      MM(KK)=0
1100 CONTINUE

```

```

C      PRINT 9000
C      LD=ALOG(2.)/(19.4*365.)
C      LE=ALOG(2.)/5.01

```

```

      LEM=ALOG(2.)/(5.01*24.*60.)
      LEH=ALOG(2.)/(5.01*24.)
      DO 10 I=1,500
      READ 2,C(I)          ,(M(I,J),J=1,15)          ,IKODE(I)
1    , (M(I,JJ), JJ=25,27),M(I,29)
      IF(EOF(5))747,1050
1050 IF(MOD(I,50).EQ.0) PRINT 9000
      PRINT 1120,C(I),(M(I,J),J=1,15)          ,IKODE(I)
1    , (M(I,JJ), JJ=25,27),M(I,29)
C
C TO INCORP. HR + MIN. ADD TO BOTH CALL STATEMENTS HR(I), EMIN(I)
C AND TO DIMENSION STATEMENT ADD HR(500), EMIN(500)
C DAY OF STUDY THAT SAMPLE COLLECTION STARTED +251
      CALL ETIME(M(I,1),M(I,2),M(I,3),A)
C DAY OF STUDY THAT SAMPLE COLLECTION ENDED +251
      CALL ETIME(M(I,4),M(I,5),M(I,6),B)
C DAY OF STUDY THAT SAMPLE PLATING ENDED + 251
      CALL ETIME(M(I,25),M(I,26),M(I,27),CC)
      M(I,19)=A-251.
      M(I,20)=B-251.
C THE FOLLOWING EXPRESSES THE ELAPSED TIME BETWEEN THE MIDPOINT OF
C SAMPLE COLLECTION AND THE END OF SAMPLE PLATING IN DAYS
      M(I,28)=M(I,20)-M(I,19)
      M(I,16)=CC-251.-M(I,20)+M(I,28)/2.
C CALC. OF RA(E) PRESENT AT BEGINNING OF COUNTING
C
C NEW CHEMICAL EFFICIENCY FOR RA(E) IN WHISKERS = .742
      IF(M(I,9).EQ..726)M(I,9)=.742
C NEW CHEMICAL EFFICIENCY FOR RA(E) IN BLOOD = .477
      IF(M(I,9).EQ..686)M(I,9)=.447
      IF ( M(I,15) .EQ. 0.0) GOTO 18
13 EN=-LEH*M(I,15)/60.
      AE=M(I,11)*M(I,15)*LEM/((1-EXP(EN))*M(I,8)*M(I,9)*M(I,10))
C
C CALC OF RA(E) PRESENT AT THE END OF PLATING
C BTPC= BETA TIME IN MINUTES BETWEEN THE END OF PLATING AND THE BEGINNING OF
C COUNTING
C

```

```

      IF(BTPC.GT.0.)GO TO 51
      BTPC=0.
51  AE=AE*EXP(LEM*BTPC)
C
C AS AE=AD,THE FOLLOWING CALCS RA(D) ACTIVITY IN DPM AT THE MIDPOINT OF
C SAMPLING
      M(I,17)=AE*EXP(-LD*M(I,16))
      GOTO 19
C
18  CONTINUE
      M(I,17) = 0.0
      AE=0.
C
19  CONTINUE
C
C CALC. OF RA(F) ACTIVITY IN DPM AT TIME OF SAMPLE COLLECTION
      IF ( M(I,14) .EQ. 0.0) GOTO 25
C CORRECTION FOR DECAY BETWEEN SAMPLE PLATING AND SAMPLE COUNTING
C THE FOLLOWING EQUATION IS THE ACTIVITY OF THE FIRST DAUGHTER WITH
C A1= RA(E) AND A2= RA(F).
C NEW CHEMICAL EFFICIENCY FOR RA(F) IN WHISKERS = .723
      IF(M(I,13).EQ..713)M(I,13)=.723
C NEW CHEMICAL EFFICIENCY FOR RA(F) IN BLOOD = .142
      IF(M(I,13).EQ..507)M(I,13)=.142
C DPMAP= DPM RA(F) AT TIME OF PLATING.
      DPMAP=M(I,14)*EXP(LF*(M(I,7)/24.+M(I,29)))/(M(I,12)*M(I,13)
C *M(I,10))-LF*AE*(EXP((LF-LE)*(M(I,7)/24.+M(I,29)))-1)/(LF-LE)
C CORRECTION FOR DECAY BETWEEN MIDPOINT OF SAMPLE COLLECTION AND SAMPLE
C PLATING
C CALC OF RA(F) ACTIVITY KNOWING RA(D) AND RA(E) ACTIVITIES AT MIDPOINT OF
C SAMPLE COLLECTION . SECOND DAUGHTER EQ. USED.
      M(I,18)=DPMAP *EXP(LF*M(I,16))-LF*LE*
      CAE *(EXP((LF-LD)*M(I,16))-1)/((LE-LD)*(LF-LD))+LF*LE*AE*
      C(EXP((LF-LE)*M(I,16))-1)/((LE-LD)*(LF-LE))
      DPMO = M(I,17)
      DPMF = M(I,18)
      IF(M(I,17).LE.0)GOTO20
C

```



```

C 12 CONTINUE
C
C      CHECK TO SEE IF CONTROL SAMPLE.
C
      IRES = C(I) .AND. MASK
      IF( IRES .NE. MASS)GOTO 950
      IF(IKODE(I).EQ.4)GOTO950
      TDPMD = TDPMD + DPMO
      TDPMF = TDPMF + DPMF
      ICONT = ICONT + 1
950  CONTINUE
10  CONTINUE
C
747 N = I - 1
      LCNT = 0
      WRITE(6,3)
      DO11 I=1,N
      LCNT = LCNT + 1
      IF( MOD( LCNT,14) .EQ. 0 ) WRITE(6,3)
      CWLF = M(I,23)
      WLF = M(I,22)
      WLD = M(I,21)
      CWLD = MM(I)
      WRITE(6,4)C(I),(M(I,J),J=1,23),CWLD      ,IKODE(I)
1   , (M(I,JJ), JJ=25,27),M(I,29)
11  CONTINUE
C
      WRITE(6,5)LD,LE,LEM,LF,LEH
      IF(ICONT .EQ. 0) CALL EXIT
      AV1 = TDPMD / FLOAT(ICONT)
      AV2 = TDPMF / FLOAT(ICONT)
      WRITE(N6,6)TDPMD, TDPMF, ICONT, AV1,AV2
      CALL EXIT
C
2   FORMAT( A5,3F2.0,1X,3F2.0,F3.0,2F4.3,F7.4,
1  F7.4,2F4.3,F7.4,1X,F4.0,I2,1X, 3F2.0,1X,F3.0)
C
3   FORMAT(1H1,////52X,*PROGRAM DPM * // 1X

```

```

C      NOTE - FOR REGRESSION EQUATIONS DERIVED BY NOEL SAVIGNAC *****
C      WLD = WORKING LEVELS DERIVED FROM REGRESSION EQUATION OF MINE WL
C      V.S. RA(D) CORRECTED FOR BACKGROUND ACTIVITY IN WHISKERS
C      CWLD = WORKING LEVELS DERIVED FROM REGRESSION EQUATION OF TLD WL
C      V.S. RA(D) CORRECTED FOR BACKGROUND ACTIVITY IN WHISKERS
C      WLF = WORKING LEVELS DERIVED FROM REGRESSION EQUATION OF MINE WL
C      V.S. RA(F) CORRECTED FOR BACKGROUND ACTIVITY IN WHISKERS
C      CWLF = WORKING LEVELS DERIVED FROM REGRESSION EQUATION OF TLD WL
C      V.S. RA(F) CORRECTED FOR BACKGROUND ACTIVITY IN WHISKERS
C
C      THE FOLLOWING EQUATION WAS DERIVED BY R. GOTCHY
C       $WLD = 0.443 * (DPMD / 2.22) ** 0.713$ 
C      AVERAGE DPMD FOR CONTROLS = .669 = .3014 PCI RA(D)
C      IF(DPMD.LE.0.669)GOTO 667
C      THE FOLLOWING EQUATION WAS DERIVED BY R. GOTCHY
C       $CWLD = 0.443 * ((DPMD - .667) / 2.22) ** 0.713$ 
C      THE FOLLOWING EQUATION WAS DERIVED BY N. SAVIGNAC FOR 0 DAY DELAY
C       $WLD = .3967 * (DPMD / 2.22 - .3014) ** .713$ 
C      THE FOLLOWING EQUATION WAS DERIVED BY N. SAVIGNAC FOR 20 DAY DELAY
C       $WLD = .413 * (DPMD / 2.22 - .3014) ** .713$ 
C      THE FOLLOWING EQUATION WAS DERIVED BY N. SAVIGNAC FOR 0 DAY DELAY
C       $CWLD = .40371 * (DPMD / 2.22 - .3014) ** .713$ 
C      GOTO21
667 WLD=CWLD=0.0
      GO TO 21
20 CONTINUE
C      NOTE, THE NEXT STATEMENT TAKES NEGATIVE VALUES OF DPMD AND SETS
C      THEM EQUAL TO ZERO.
      WLD=CWLD=DPMD=0.0
      M(I,17) = 0.0
      IF(IKODE(I).EQ.4)GOTO21
      IKODE(I)=8
21 CONTINUE
      IF(DPMF.LE.0) GO TO 707
C      THE FOLLOWING EQUATION WAS DERIVED BY R. GOTCHY
C       $WLF = 0.246 * (DPMF / 2.22) ** 0.691$ 
C      AVERAGE DPMF FOR CONTROLS = 1.168 = .5261 PCI RA(F)

```

```

C THE FOLLOWING EQUATION WAS DERIVED BY R. GOTCHY
C  $CWLF = 0.246 * ((DPMF - 1.168) / 2.22) ** 0.691$ 
C THE FOLLOWING EQUATION WAS DERIVED BY N. SAVIGNAC FOR 0 DAY DELAY
C  $WLF = .4612 * (DPMF / 2.22 - .5261) ** .691$ 
C THE FOLLOWING EQUATION WAS DERIVED BY N. SAVIGNAC FOR 20 DAY DELAY.
C  $WLF = .477 * (DPMF / 2.22 - .5261) ** .691$ 
C THE FOLLOWING EQUATION WAS DERIVED BY N. SAVIGNAC FOR 0 DAY DELAY
C  $CWLF = .72805 * (DPMF / 2.22 - .5261) ** .691$ 
GO TO 7090
66 WLF=CWLF=0.0
GO TO 7090
C NOTE, THE NEXT STATEMENT TAKES NEGATIVE VALUES OF DPMF AND SETS
C THEM EQUAL TO ZERO.
707 CWLF=WLF=DPMF=0.0
M(I,18) = 0.0
IF(IKODE(I).EQ.4)GOTO7090
IF(IKODE(I).EQ.8) IKODE(I)=10
IF(IKODE(I).EQ.10) GO TO 7090
IKODE(I)=9
7090 CONTINUE
M(I,22) = WLF
M(I,23) = CWLF
M(I,21) = WLD
MM(I) = CWLD
GOTO 9
C
25 CONTINUE
M(I,18) = 0.0
CWLF = WLF = 0.0

9 CONTINUE
C
C PUNCH OUT DATA
C
PUNCH 1970,DPMF,DPMF,M(I,19),M(I,20),C(I),IKODE(I)
C THE NEXT TWO STATEMENTS BELONG TO PUNCH 1971 ONLY.
C ITEST(I)=IKODE(I)+1
C GOTO(14,12,12,12,12,12,12,12,14,14,14)ITEST(I)

```

```

2/36X*IKODE=2 NO RA(E) DETERMINATION. *
3/36X*IKODE=3 NO RA(F) DETERMINATION. *
4/36X*IKODE=4 SUSPECTED RA(F) CONTAMINATION.*
5/36X*IKODE=5 INSTRUMENT MALFUNCTION IN RA(E) DETERMINATION.*
6/36X*IKODE=6 STIRRING MOTOR FAILURE. *
X/36X*IKODE=7 SAMPLE LEAKED DURING PLATING.*
X/36X*IKODE=8 DPM RA(D) CALC TO BE NEG AND RESET = 0.0.*
X/36X*IKODE=9 DPM RA(F) CALC TO BE NEG AND RESET = 0.0.*
X/36X*IKODE=10 DPM RA(D) + DPM RA(F) NEG AND RESET = 0.0.*//1X
7*CODE COLLECTION DATE BT CTB CMB WEIGHT OB CPMB CTEA CMEA O
8B CPMA BCT TCP DPM RA(D) DPM RA(F) START STOP WLD WLF CWLF
1 */)

```

```

C
4 FORMAT(1H ,A5, F3.0,F3.0,F3.0,2X,F3.0,F3.0,F3.0,1X,
1F4.0,1X,F4.3,1X,F4.3,1X,F7.4,1X,F6.4,1X,F4.3,1X,F4.3,1X,F7.4,
C1X,F5.0,1X,F5.0,2X,F8.4,2X,F8.4,2X,F4.0,1X,F4.0,1X,F5.2,1X,F5.2,
11X,F5.2,/,29X,*CWLD =*,F5.2,* IKODE=* 12,* PLATING TIME= *
1 3F3.0,* TBBA= * F4.0)

```

```

C
5 FORMAT(1H1,/* DECAY CONSTANTS LD = *,E15.8, * LE = *,E15.8, * LEM
C = *,E15.8, * LF = *,E15.8,* LEM = *,E15.8)

```

```

C
6 FORMAT(1H ,/1X, *TOTAL DPMD = * F10.5 , 1X,
1 / 1X, *TOTAL DPMF = * F10.5 , 1X,
2 / 1X, *NO. OF CONTROL SAMPLES = * 13 , 1X,
3 / 1X, *AVERAGE DPMD/SAMPLE = * F10.5 , 1X,
4 / 1X, *AVERAGE DPMF/SAMPLE = * F10.5 , 1X,/)

```

```

1120 FORMAT(1H ,
1A5,F4.0,1X,F4.0,1X,F4.0,2X,F4.0,1X,F4.0,1X,F4.0,
2F4.0,1X,F4.3,1X,F4.3,1X,F7.4,1X,F6.4,1X,F4.3,1X,F4.3,1X,F7.4,1X,
3F6.0 ,1X,12,1X,3F3.0,1X,F4.0)

```

```

C
1970 FORMAT( 2F10.3,20X,2F5.0,A5,17X,12)

```

```

C
C1971 FORMAT(3F10.4,10X,2F5.0,A5,2X,F15.4)

```

```

C
9000 FORMAT(1H1, // 59X, *INPUT CARDS * // )

```

```

      SUBROUTINE ETIME(MON, DAY, IYR, ETDO)
C TO INCORP. HR + MIN ADD TO DIMENSION HR(100), EMIN(100) AND TO
C STATEMENT 839 ADD +HR(1)/24.0 + EMIN(1)/1440.0 ALSO ADD TO SUBROUTINE
C ETIME HR, EMIN
      REAL MON, IYR
      FEBR=0.0
      IF(IYR.EQ.0) GO TO 840
      IIYR=IYR-67
      GO TO (821,822,823,824,825,826,927)IIYR
927 EYD=2192.0
      GO TO 827
821 EYD=0.0
      FEBR=1.0
      GO TO 827
822 EYD=366.0
      GO TO 827
823 EYD=731.0
      GO TO 827
824 EYD=1096.0
      GO TO 827
825 EYD=1461.0
      FEBR=1.0
      GO TO 827
826 EYD=1827.0
827 IMON = IFIX(MON)
      GO TO(828,829,830,831,832,833,834,835,836,837,838,939)IMON
939 EMD=334.0+FEBR
      GO TO 839
828 EMD=0.0
      GO TO 839
829 EMD=31.0
      GO TO 839
830 EMD=59.0+FEBR
      GO TO 839
831 EMD=90.0+FEBR
      GO TO 839
832 EMD=120.0+FEBR
      GO TO 839

```

GO TO 839
834 EMD=181.0+FEBR
GO TO 839
835 EMD=212.0+FEBR
GO TO 839
836 EMD=243.0+FEBR
GO TO 839
837 EMD=273.0+FEBR
GO TO 839
838 EMD=304.0+FEBR
839 ETDO=EYD+EMD+DAY-1.0
RETURN
840 ETDO = 252.0
RETURN
END

Table D.2. A listing of Program SORT

JLIMITS,CM120000,T199,PR99,MT1.1V501TF,
RFL(45000)
FTN.
RFL(100)
RFL(120000)
LGO.
RFL(100)
REQUEST,TAPES,LD.D219,WRITE.SAVIGNAC/RAD. BIOLOGY
RFL(120000)
SORTMRG.


```
PROGRAM SORT (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
```

SORT ORDER.

FIRST SORT.

SORT CODE(INDICATES SOURCE OF DATA) COLS. 56-57
 INTO ASCENDING ORDER.

SECOND SORT.

17. SORT START DATES, COLS. 41-44 INTO ASCENDING ORDER.

THIRD SORT.

SORT MINERS INITIALS TO GET ALL DATA FOR ONE MINER TOGETHER.

TAPES IS FILE FROM WHICH CARDS ARE READ.

TAPE2 IS FILE ONTO WHICH EDITED CARDS ARE WRITTEN.

REAL RJM(3000)

REAL W(3000,6)

COMMON ISET(3000)

```

DIMENSION IKODE(3000)

```

READ ALL CARDS INTO STORAGE ARRAYS.

DO 17 I=1,3000

```
READ(5,2) (W(I,J),J=1,6), ISET(I), RJM(I) , IKODE(I)
```

```
IF (EOF(5).NE.0) GO TO 3
```

CHANGE -0 TO 0.(LOOKS NICE ON PRINTOUT).

```
IF(ISET(I).EQ.0) ISET(I) = 0
```

```
IF(IKODE(I) .EQ. 0) IKODE(I)=0
```

17 CONTINUE

```

C   THE DATA FOR PROGRAM SORT GOES HERE.
C   PRINT OUT HOW MANY CARDS WERE READ IN.
C
3  NSAMP = I-1
   PRINT 9000,NSAMP

   DO 25 L=1,NSAMP
     IF(ISET(L).NE.2) GO TO 41
C
C       IF UMH MINE DATA READ IN AND START DATE IS ZERO SET START
C       DATE TO 1.0.
C
     IF(W(L,4).EQ.0) W(L,4) = 1.0
     GO TO 35
C
C       IF ANY OTHER SAMPLE AND START DATE IS ZERO, SET START DATE
C       EQUAL TO STOP DATE.
C
41  IF(W(L,4).EQ.0) W(L,4) = W(L,5)
35  CONTINUE
C
C   PRINT OUT DATA ONTO FILE2.
C
      WRITE(2,4) (W(L,J),J=1,6),ISET(L),RJM(L) ,IKODE(L)
25  CONTINUE

      ENDFILE 2
      REWIND 2
      CALL EXIT
      2  FORMAT(3F10.2,10X,2F5.0,A5,I1,F15.4,I2)
      4  FORMAT(3F10.2,10X,2F5.0,A5,I2,F15.4,I2).
9000 FORMAT(1H , * NSAMP IS * I6 //)
      END

```

7-10-68

Table D.3. A listing of Program AV-PL

JEIMITS,CM70000,T200,PR200,PU999,MT1.7V5V005,

RFL(43000)

FTN.

REQUEST,TAPE5,LO.D114,READ.

RFL(100)

RFL(70000)

LGO.

REWIND(TAPE3)

COPYCF(TAPE3)

REWIND(TAPE3)

COPYCF(TAPE3,FILMPR)

EXIT.

REWIND(TAPE3)

COPYCF(TAPE3)

REWIND(TAPE3)

COPYCF(TAPE3,FILMPR)

```

NRANGE = 50
DAYS(1) = 5.0
DO 100 K=1,50
DAYS(K+1) = DAYS(K) + 10.0
100  CONTINUE
RANGE(1) = 10.0
DO 110 K = 1, NRANGE
RANGE(K+1) = RANGE(K) + 10.0
110  CONTINUE
GOTO 170

C
C      30 DAY AVERAGES
C
150  CONTINUE
NRANGE = 17
KVAL = 2
DAYS(1) = 15.0
DO 160 K=1,NRANGE
DAYS( K + 1 ) = DAYS(K) +30.0
160  CONTINUE
C
RANGE(1) = 30.0
DO 161 K = 1, NRANGE
RANGE(K+1) = RANGE(K) + 30.0
161  CONTINUE
GOTO 170

C
C      90 DAY AVERAGES.
C
162  CONTINUE
NRANGE = 6
KVAL = 3
DAYS(1) = 45.0
DO 164 K = 1, NRANGE
DAYS( K + 1 ) = DAYS(K) + 90.0
164  CONTINUE

RANGE(1) = 90.0

```



```

C  RANGE. RANGE( K+1) = RANGE(K) + 90.0
165 CONTINUE
C
170 CONTINUE
      INIT = 10H          $  IFIRST = 0  $  N6 = 6  $  N5 = 5
      N5 = 5
C
      DELDAY      FACTOR ADDED TO START AND STOP DATES.
C
      DELDAY = 0.0
      PRINT 1655
C
200 CONTINUE
      READ(N5,9000) (CARD(I),I=1,6),ISV,(CARD(K),K=7,9) ,IKODE
      IF(EOF(N5) .NE. 0.0)      GOTO 600
C
      CHECK FOR BLOOD SAMPLE.
      AND CONTROL.
C
      IF( ICARD(7) .EQ. 1RB ) GOTO 200
      IF ( ICARD(7) .EQ. 1RC) GO TO 200
      GO TO 220
C
      CHECK MINERS INITIAL.
C
      DO 202 K=1,5
      IF ( INITIAL(K) .EQ. ICARD(6)) GOTO 220
202 CONTINUE
      GO TO 200
C
220 CONTINUE
      IMN = 0
C
      PRINT 9000,(CARD(I),I=1,6),ISV,(CARD(K),K=7,9) ,IKODE
      ICODE = IFIX( CARD(8) + 1.0 )
C
      TIME TO PLOT,IE INITIALS CHANGE.
C

```

```
IF(ICARD(6) .NE. INIT .AND. IFIRST .NE. 0 ) CALL PLOTS(INIT)  
INIT =ICARD(6) $ IFIRST = IFIRST + 1
```

```
COMPUTE AVERAGES.
```

```
GO TO(300,400,500,500) ICODE
```

```
300 CONTINUE  
CALL SUMS(WLDAV,WLDTOT,CARD(4),CARD(5),CARD(1),1)
```

```
IF KODE = 4 IGNORE DPMF(WLFAV)
```

```
CALL SUMS(WLFAV,WLFTOT,CARD(4),CARD(5),CARD(2),2)
```

```
GO TO 200
```

```
CALL SUMS(CWLFAV,CWLFTOT,CARD(4),CARD(5),CARD(3),3)
```

```
CALL SUMS(CWLDAV,CWLDTOT,CARD(4),CARD(5),CARD(9),6)  
GOTO 200
```

```
400 CONTINUE  
CARD(4) = CARD(4) + DELDAY  
CARD(5) = CARD(5) + DELDAY  
CALL SUMS(TLDAV,TLDTOT,CARD(4),CARD(5),CARD(1),4)  
GOTO 200
```

```
500 CONTINUE  
CARD(4) = CARD(4) + DELDAY  
CARD(5) = CARD(5) + DELDAY  
IF(CARD(4).NE.1.0) CARD(4) = CARD(4) + 1.0  
IMN = 1  
CALL SUMS(MINEAV,MINETOT,CARD(4),CARD(5),CARD(1),5)  
IMN = 0  
GOTO 200
```

```
600 CONTINUE
```

```

      CALL PLOTS(INIT)
      REWIND 5
      GOTO 7000
      GO TO(150, 162, 7000) KVAL
C
7000  CONTINUE
      STOP7
8000  FORMAT(1H ,/* CARD * 3F10.3, 2F5.0, R2, A3, F2.0/)
C
1655  FORMAT(1H1)
9000  FORMAT(3F10.3,10X,2F5.0,R2,A2,R1,F2.0,F15.4,12)
      END
      SUBROUTINE PLOTS(INIT)
C
C      ALL THIS S/R DOES IS PRINT RESULTS ONTO OUTPUT FILE
C      AND PUNCH OUT BCD CARDS IF REQUIRED.
C
      REAL NOEL
      COMMON /VAR1/ WLDAV(50),WLF(50),CWL(50),MINEAV(50),
1 TLDAV(50),CWLDAV(50)
      COMMON /VAR2/ WLDTOT(50),WLFTOT(50),CWLFTOT(50),MINETOT(50),
1 TLDTOT(50),CWLDTOT(50)
      COMMON /NOEL/ NOEL(50,6)
      COMMON /VAR3/ PLDAYS(50),DAYS(50)
      COMMON /CARD/ CARD(9),DCARD(50)
      COMMON /INIT/ KINIT
      COMMON / RANGE / RANGE(51), N RANGE
C
      DATA PAGE / 0.0 /
C
C      PRINT OUT REQUIRED DATA.
C
      KINIT = INIT
      N6 = 6
      IF(AMOD(PAGE,2.0) .EQ. 0.0)      WRITE(N6,9030)
      PAGE = PAGE + 1.0
      WRITE(N6,9020) INIT
      WRITE(N6,9000)

```

```

C
C
1T(I),NOEL(I,2),I=1,NRANGE)
C
C
WRITE(N6,9020) INIT
WRITE(N6,9099)
WRITE(N6,9010) (DAYS(I),
1TLDAV(I),TLDTOT(I),NOEL(I,4),MINEAV(I),MINETOT(I),NOEL(I,5),
2I=1,NRANGE)
C
C
PUNCH OUT REQUIRED DATA, SEE COMMENTS IN MAIN PROGRAMME.
C
DO 100 I = 1, NRANGE
PUNCH 9060,INIT,DAYS(I),WLDAV(I), WLDTOT(I), WLFAY(I), WLFTOT(I),
1 TLDAV(I),TLDTOT(I),MINEAV(I),MINETOT(I)
100 CONTINUE
C
C
ZERO OUT ARRATS.
C
DO 1777 K=1,50
DO 1777 KK=1,6
1777 NOEL(K,KK) = 0.0
CALL ZERO(WLEAV,900)
RETURN
C
1655 FORMAT(1H1)
9000 FORMAT(1H ,//13X* DAYS          WLDAV      WLDDAY      WLDTOT      WLFAY
1      WLFDAY      WLFTOT*//)
C
9010 FORMAT(7X,7F11.2)
C
9020 FORMAT(1H1,/,54X,*INITIALS ARE *,R2,/)
9030 FORMAT(1H )
9060 FORMAT( R2,F6.0, 8F9.3 )
9099 FORMAT(1H ,12X,*DAYS          TLDAV      TLDDAY      TLDTOT      MINEAV
1      MINEDAY      MINETOT*//)
END
SUBROUTINE ZERO(ARRAY,N)
C

```

```

C      DIMENSION ARRAY(1)
C
C      DO 100 K=1,N
C      ARRAY(K) = 0.0
100  CONTINUE
C      RETURN
C      END
C      SUBROUTINE SUMS(AVERAGE,TOTAL,START1,STOP1,VALUE ,II)
C
C      S/R COMPUTES RADIATION LEVELS FOR 10,30,90 DAY AVERAGES.
C      LOOK IN COMMON BLOCK /RANGE/ FOR VALUES.
C
C      AVERAGE  ARRAY WHERE MONTHLY AVERAGES ARE STORED.
C      TOTAL     ARRAY WHERE MONTHLY TOTALS ARE STORED.
C      START     FIRST DAY OF STUDY.
C      STOP      LAST DAY OF STUDY.
C      VALUE     MEASUREMENT RECORDED.
C
C      REAL NOEL
C
C      DIMENSION AVERAGE(1),TOTAL(1)
C      COMMON /NOEL/ NOEL(50,6)
C      COMMON /MINE/ IMN
C      COMMON / RANGE / RANGE(51), NRANGE
C
C      N6 = 6
C      J = 1
C      START = START1  $  STOP = STOP1
C
C      50  CONTINUE
C          DO 100 K = J, NRANGE
C          IF(START .LE. RANGE(K))      GOTO 200
C      100  CONTINUE
C          GOTO 400
C
C      200  CONTINUE
C          IF(IMN.NE.1) GO TO 702

```

```

      GO TO 707
702  CONTINUE
      DELTA = RANGE(K) - START + 1.0
707  CONTINUE
      IF(STOP .LE. RANGE(K))          DELTA = STOP - START + 1.0
C
      AVERAGE(K) =(DELTA * VALUE + AVERAGE(K) * TOTAL(K))
C
C      1      -----
C              /(DELTA + TOTAL(K))
C
      TOTAL(K) = DELTA + TOTAL(K)
      NOEL(K,II) = NOEL(K,II) + (VALUE*DELTA)
C
C
C
      IF(STOP .LE. RANGE(K))          GOTO 400
      START = RANGE(K)  $  J = K + 1
      START = START + 1.0
      GOTO 50
C
400  CONTINUE
      RETURN
      END
      SUBROUTINE PLACE(HOLD,IST,FROM,NO)
      DIMENSION HOLD(1),FROM(1)
C
C      S/R STORES DATA IN ARRAYS.
C
C      HOLD  ARRAY INTO WHICH VALUES ARE TO BE STORED.
C      IST   FIRST FREE POSITION IN HOLD.
C      FROM  ARRAY FROM WHICH VALUES ARE TO BE TAKEN.
C      NO    NO. OF VALUES TO BE STORED.
C
      I = IST
      DO 100 J=1,NO
      HOLD(I) = FROM(J)
      I = I + 1
100  CONTINUE

```

END

SUBROUTINE PLOT (NO,A,N,M,NFUNC,FUNC,XLAX,XLIN,YLAX,YLIN)

PLOT0000

PURPOSE - TO PLOT A GRAPH WITH ONE INDEPENDENT VARIABLE AND UP
TO 9 DEPENDENT VARIABLES, WITH THE ADDITIONAL ABILITY TO PLOT A
CALCULATED CURVE. THE INDEPENDENT VARIABLE IS PLOTTED ON A
HORIZONTAL AXIS, THE DEPENDENT ONES ON A VERTICAL AXIS. WIDTH
IS 100 PRINT POSITIONS, HEIGHT IS 50. EVERY POINT OF EACH
DEPENDENT VARIABLE IS INDICATED BY A NUMBER (1-9), WHILE THE
CALCULATED POINTS ARE DENOTED BY ASTERISKS.

PLOT0010
PLOT0020
PLOT0030
PLOT0040
PLOT0050
PLOT0060
PLOT0070

PARAMETER USAGE.

PLOT0080

NO A FIXED POINT NUMBER, UP TO 3 DIGITS, PRINTED AS THE
CHART NUMBER

PLOT0090
PLOT0100

A A VECTOR WHOSE FIRST N POSITIONS CONTAIN THE INDEPENDENT
VARIABLE, AND WHOSE NEXT M SETS OF N POSITIONS CONTAIN
THE DEPENDENT VARIABLES

PLOT0110
PLOT0120
PLOT0130

N NUMBER OF OBSERVATIONS

PLOT0140

M NUMBER OF VARIABLES (INDEPENDENT + DEPENDENT)

PLOT0150

NFUNC GREATER THAN ZERO IF A CALCULATED CURVE IS TO BE
PRINTED

PLOT0160
PLOT0170

FUNC SUBROUTINE TO GENERATE CALCULATED CURVE. IF ONE WANTED.
ELSE IS A DUMMY. PROGRAM CALLING PLOT MUST HAVE AN
EXTERNAL FUNC. SUBROUTINE CALLED BY CALL FUNC (X,Y),
WHERE X IS GIVEN TO SUBROUTINE AND Y RETURNED.

PLOT0180
PLOT0190
PLOT0200
PLOT0210

XLAX,XLIN,YLAX,YLIN MAXIMUM AND MINIMUM VALUES OF THE
INDEPENDENT AND DEPENDENT VARIABLES TO BE USED IN THE
PLOT IF XLAX = XLIN, THE PROGRAM CALCULATES ITS OWN
MAXIMUM AND MINIMUM FOR THE INDEPENDENT VARIABLE.

PLOT0220
PLOT0230
PLOT0240
PLOT0250

SIMILARLY FOR YLAX = YLIN

PLOT0260

REQUIRED SUBROUTINES. FUNC (IF USED), AND SCAL.

PLOT0270

DIMENSION IOUT(101),XPR(11),A(1),CALC(102)

PLOT0280

CALC IS 1 LARGER THAN NEEDED IN CASE XMIN + 100*XSCAL

PLOT0290

SHOULD BE LARGER THAN XMAX. THIS PREVENTS SLOPOVER INTO

PLOT0300

NEXT LOCATION. LOOK AROUND CARD =950 TO SEE WHAT I MEAN.

PLOT0310

CALC IS WHERE CALCULATED FUNCTION GOES.

PLOT0320

INTEGER ISYM(5)

INTEGER IPR(11)

COMMON /INIT/ INIT
COMMON ISYM

C

EQUIVALENCE (IDOUT(1),XPR(1))

PLOT0330

C

1 FORMAT(1H1,100X,*MINERS INITIALS=*,2X,R2,//////)
2 FORMAT(1H ,F12.3,*+ *,101A1)
7 FORMAT(1H ,14X,10(*+.....*),1H+)
8 FORMAT(1H0,9X,11(I7,3X))
118 FORMAT(1H ,12X,2H- ,101A1)
737 FORMAT(1H 2X,*WL*,F8.3,*+ *,101A1)
992 FORMAT(1H-,///,53X,*DAY OF STUDY*,/)
1970 FORMAT(1H+,14X,101A1)

C

C

PRINT CHART NO.

PLOT0390

C

WRITE(3,1) INIT

ICOUNT = 4

C

IF NO EXTREMES OF X GIVEN, FIND THEM

IF (XLAX - XLIN) 20,10,20

10 XMIN = A(1)

XMAX = XMIN

DO 15 J = 1,N

IF (A(J) - XMIN) 11,12,12

12 IF (A(J) - XMAX) 15,15,14

11 XMIN = A(J)

GO TO 15

14 XMAX = A(J)

15 CONTINUE

GO TO 202

20 XMAX=XLAX

XMIN=XLIN

C

CALCULATE RAW SCALE SIZE

202 XSCAL=(XMAX-XMIN)/100.

C

ROUTINE TO CALCULATE EXACT SCALE SIZE AND END POINTS

CALL SCAL (XSCAL,XMAX,XMIN)

C

IF NO EXTREMES OF Y GIVEN, FIND THEM

IF (YLAX - YLIN) 110,112,110

PLOT0410

PLOT0420

PLOT0430

PLOT0440

PLOT0450

PLOT0460

PLOT0470

PLOT0480

PLOT0490

PLOT0500

PLOT0510

PLOT0520

PLOT0530

PLOT0540

PLOT0550

PLOT0560

PLOT0570

PLOT0580

PLOT0590

PLOT0600

PLOT0610

YMIN = A(L)	PLOT0630
YMAX=YMIN	PLOT0640
LL = M*N	PLOT0650
DO 40 J = L,LL	PLOT0660
IF(A(J)-YMIN) 28,26,26	PLOT0670
26 IF(A(J)-YMAX) 40,40,30	PLOT0680
28 YMIN=A(J)	PLOT0690
GO TO 40	PLOT0700
30 YMAX=A(J)	PLOT0710
40 CONTINUE	PLOT0720
GO TO 201	PLOT0730
110 YMAX=YMAX	PLOT0740
YMIN=YMIN	PLOT0750
C GET SCALE SIZE AND END POINTS	PLOT0760
201 YSCAL = (YMAX - YMIN) / 50.	PLOT0770
CALL SCAL (YSCAL,YMAX,YMIN)	PLOT0780
C PRINT TOP SCALE	PLOT0790
XPR(1) = XMIN	PLOT0800
DO 200 JP=1,10	PLOT0810
XPR(JP+1) = XPR(JP) + XSCAL * 10.	PLOT0820
C TO MAKE SURE THAT ZERO REALLY PRINTS AS ZERO, NOT A SMALL NUMBER	PLOT0830
C CAUSED BY ROUNDING ERRORS.	PLOT0840
IF (ABS(XPR(JP+1) - .5 * XSCAL)) 240,240,200	PLOT0850
240 XPR(JP+1) = 0.	PLOT0860
200 CONTINUE	PLOT0870
C IF CALCULATED CURVE WANTED GET VALUES BETWEEN XMIN AND XMAX	PLOT0900
IF (NFUNC) 210,210,211	PLOT0910
211 F = XMIN	PLOT0920
JP = 1	PLOT0930
213 CALL FUNC(F,CALC(JP))	PLOT0940
IF (F - XMAX) 212,210,210	PLOT0950
212 F = F + XSCAL	PLOT0960
JP = JP + 1	PLOT0970
GO TO 213	PLOT0980
210 CONTINUE	PLOT0990
C START PRINT AT MAXIMUM Y	PLOT1000
YPR = YMAX	PLOT1010
C CLEAR PRINT LINE	PLOT1020

55	IOUT(JP) = 10H	PLOT1050
C	IF CALCULATED CURVE WANTED SET UP POINTS	PLOT1060
	IF (NFUNC) 214,214,215	PLOT1070
215	F = XMIN	PLOT1080
C	SCAN ALL VALUES OF Y FOR X BETWEEN XMIN AND XMAX	PLOT1090
	JP = 1	PLOT1100
C	IS POINT WITHIN HALF A SCALE OF PRINT POSITION	PLOT1110
220	IF (ABS(YPR-CALC(JP)) - .5 * YSCAL) 216,217,218	PLOT1120
C	IF EXACTLY BETWEEN PRINT POSITIONS ONLY PRINT IT ONCE	PLOT1130
217	IF (YPR - CALC (JP)) 218,216,216	PLOT1140
C	BELIEVE IT OR NOT THIS IS AN ASTERISK (NUMBER TOO LARGE TO WRITE	PLOT1150
C	AS ONE NUMBER)	
216	IOUT(JP) = ISYM(1)	
218	IF (F - XMAX) 219,214,214	PLOT1170
219	JP = JP + 1	PLOT1180
	F = F + XSCAL	PLOT1190
	GO TO 220	PLOT1200
C	RUN DOWN EACH SET OF DEPENDENT VARIABLES	PLOT1210
C	IF NO POINTS WANTED	PLOT1220
214	IF (N) 70,70,300	PLOT1230
300	CONTINUE	
	IOUT(1) = 10H	
	WRITE(3,118) IOUT	
	DO 221 J = 2,M	
	DO 222 L = 1,N	PLOT1250
C	CALCULATE SUBSCRIPT FOR A	PLOT1260
	LL = (J - 1) * N + L	PLOT1270
C	IS IT WITHIN HALF A SCALE OF PRINT POSITION	PLOT1280
	IF (ABS(YPR - A(LL)) - .5 * YSCAL) 223,224,225	PLOT1290
C	IF EXACTLY HALFWAY BETWEEN, PRINT ONLY ONCE	PLOT1300
224	IF (YPR - A(LL)) 225,223,223	PLOT1310
C	FIND HORIZONTAL POSITION	PLOT1320
223	JP = (A(L) - XMIN) / XSCAL + 1.5	PLOT1330
C	IF OFF GRAPH, FORGET IT	PLOT1340
	IF (JP - 1) 225,226,226	PLOT1350
226	IF (JP - 101) 227,227,225	PLOT1360
C	THIS GIVES 1,2,3 ETC. FOR J=2,3,4 ETC	PLOT1370

```

      IOUT(1) = 10H
      WRITE(3,1970) IOUT
      DO 1977 KKK = 1,101
1977 IOUT(KKK) = 1H
      225 CONTINUE
      222 CONTINUE
      221 CONTINUE
      70 ICOUNT = ICOUNT + 1
C      PRINT VALUE ON VERTICAL AXIS EVERY FIVE POSITIONS
      IF (ICOUNT - 5) 120,119,120
      120 CONTINUE
      GO TO 80
C      MAKE ZERO PRINT AS ZERO, NOT SMALL NUMBER
      119 IF (ABS(YPR) - .5 * YSCAL) 232,232,233
      232 F = 0.
      GO TO 234
      233 F = YPR
      234 IF((F-1.5).LT.0.1.AND.F.GT.1.0) GO TO 707
      WRITE(3,2) F,IOUT
      GO TO 747
      707 WRITE(3,737) F,IOUT
      747 CONTINUE
      ICOUNT = 0
C      IF REACHED YMIN, STOP
      80 IF (YPR - YMIN) 86,86,45
C      ELSE DECREMENT Y
      45 YPR = YPR - YSCAL
      GO TO 230
      86 WRITE (3,7)
C      PRINT BOTTOM SCALE
      XPR(1) = XMIN
      DO 90 JP = 1,10
      XPR(JP+1) = XPR(JP) + XSCAL * 10.
      IF (ABS(XPR(JP+1) - .5 * XSCAL)) 231,231,90
      231 XPR(JP+1) = 0.
      90 CONTINUE
      DO 175 KK = 1,11
      175 IPR(KK) = XPR(KK)

```

PLOT1390
 PLOT1400
 PLOT1410
 PLOT1420
 PLOT1430
 PLOT1440

PLOT1460
 PLOT1470
 PLOT1480
 PLOT1490
 PLOT1500
 PLOT1510

PLOT1530
 PLOT1540
 PLOT1550
 PLOT1560
 PLOT1570
 PLOT1580
 PLOT1590
 PLOT1600
 PLOT1610
 PLOT1620
 PLOT1630
 PLOT1640
 PLOT1650
 PLOT1660

	WRITE(3,992)	
	RETURN	PLOT1680
	END	PLOT1690
	SUBROUTINE SCAL (XSCAL,XMAX,XMIN)	PLOT1700
	PURPOSE. GIVEN RAW SCALE AND END POINTS, GET ROUNDED VALUES.	PLOT1710
	F=ALOG10(XSCAL)	PLOT1720
	FIND NEXT LOWEST POWER OF 10.	PLOT1730
	IF (F) 1,2,2	PLOT1740
	IF NEGATIVE, STOP FORTRAN FROM ROUNDING UP	PLOT1750
1	JP=F-1	PLOT1760
	GO TO 20	PLOT1770
2	JP=F	PLOT1780
	FIND VALUE JUST LARGER THAN TAW YSCAL, OF FORM 1,2,2.5,2,OR 10	PLOT1790
	TIMES 10 TO AN INTEGRAL POWER	PLOT1800
20	F=10.**JP	PLOT1810
6	IF (F-XSCAL) 3,4,4	PLOT1820
3	F=F+F	PLOT1830
	IF (F-XSCAL) 5,4,4	PLOT1840
5	F=1.25*F	PLOT1850
	IF (F-XSCAL) 7,4,4	PLOT1860
7	F=F+F	PLOT1870
	IF (F-XSCAL) 30,4,4	PLOT1880
30	F=F+F	PLOT1890
	GO TO 6	PLOT1900
	SET EQUAL TO SCALE	PLOT1910
4	XSCAL=F	PLOT1920
	JP=XMAX/XSCAL	PLOT1930
	MAKE END POINTS INTEGRAL MULTIPLES OF SCALE	PLOT1940
12	F=JP*XSCAL	PLOT1950
	IF (F-XMAX) 10,11,11	PLOT1960
10	JP=JP+1	PLOT1970
	GO TO 12	PLOT1980
11	XMAX=F	PLOT1990
	JP=XMIN/XSCAL	PLOT2000
13	F=JP*XSCAL	PLOT2010
	IF (F-XMIN) 14,14,15	PLOT2020

```

GO TO 13
14 XMIN=F
RETURN
END
SUBROUTINE PLOT1(INIT)

```

```

PLOT2040
PLOT2050
PLOT2060
PLOT2070

```

```

INTEGER ANG(5)
REAL NOEL

```

```

REAL AMAR(900)

```

```

COMMON /CARD/ CARD(9),DCARD(20)
COMMON /INIT/ KINIT
COMMON /KVAL/KVAL
COMMON /LIMITS/ DAYVAL(3)
COMMON /NOEL/ NOEL(20,6)
COMMON / RANGE / RANGE(51), N RANGE
COMMON /VAR1/ WLDAV(50),WLFAV(50),CWLFAV(50),MINEAV(50),
1 TLDAV(50),CWLDAV(50)
COMMON /VAR2/ WLDTOT(50),WLFTOT(50),CWLFTOT(50),MINETOT(50),
1 TLDTOT(50),CWLDTOT(50)
COMMON /VAR3/ PLDAYS(50),DAYS(50)

```

```

COMMON ANG

```

```

DATA DAYVAL/5.0, 11.0, 32.0/
DATA PAGE / 0.0 /

```

```

PLOT SYMBOLS

```

```

WLD      *
WLF      $
MINE     +
TLD      0

```

```

POINTS WILL NOT APPEAR ON THE GRAPHS IF THE NUMBER OF DAYS USED TO
CALC THE AVE IS LESS THAN 32 FOR THE 90 DAY AVE, LESS THAN 11 FOR THE
30 DAY AVE, OR LESS THAN 5 FOR THE 10 DAY AVE.

```

C CODE = 0 IS A BIOASSAY SAMPLE
 C CODE = 1 IS A TLD SAMPLE
 C CODE = 2 IS A UNH MINE SAMPLE
 C CODE = 3 IS A KERR MCGEE MINE SAMPLE
 C FOR CODE 0 THE DATA IS PRESENTED IN THE FOLLOWING ORDER FROM LEFT TO RIGHT
 C WL FROM RA-D USING MINE VS RA-D REGRESSION EQUATION, WL RA-F USING MINE
 C VS RA-F REGRESSION EQUATION,
 C WL FROM RA-F USING TLD VS RA-F REGRESSION EQUATION, START DAY, STOP DAY,
 C INITIALS, BATCH NUMBER, CODE, WL RA-D USING TLD VS RA-D REGRESSION EQ.
 C FOR CODE 1 * WL FROM TLD SAMPLES, BLANK, BLANK, START DAY, STOP DAY,
 C INITIALS, CODE, NONSENSE
 C FOR CODE 2 + 3 * WL FROM MINE COMPANY SAMPLES, BLANK, BLANK, START DAY,
 C STOP DAY, INITIALS, CODE, BLANK
 C

ANG(1) = 10H*****
 ANG(2) = 10H\$\$\$\$\$\$\$\$
 ANG(3) = 10H++++++
 ANG(4) = 10HC000000000
 ANG(5) = 10H/////////
 ANG(6) = 10H=====

C
 KINIT = INIT
 N6 = 6
 PAGE = PAGE + 1.0

C
 C ELIMINATE TESTS WITH SHORT TEST PERIODS.
 C

DAYMAX = DAYVAL(KVAL)
 DO 800 KK = 1, NRANGE
 IF (WLDTOT (KK) .LT. DAYMAX) WLDV (KK) = 100.0
 IF (WLFTOT (KK) .LT. DAYMAX) WLFV (KK) = 100.0
 IF (MINETOT (KK) .LT. DAYMAX) MINEV (KK) = 100.0
 IF (TLDTOT (KK) .LT. DAYMAX) TLDV (KK) = 100.0
 800 CONTINUE

C
 CC PLOT DATA POINYS.
 C

N1 = 1

```
N1 = N1 + NRANGE
CALL PLACE(AMAR, N1, WLDV , NRANGE)
N1 = N1 + NRANGE
CALL PLACE(AMAR, N1, WLFV , NRANGE)
N1 = N1 + NRANGE
CALL PLACE(AMAR, N1, MINEAV, NRANGE)
N1 = N1 + NRANGE
CALL PLACE(AMAR, N1, TLDV , NRANGE)
IPAGE = IFIX(PAGE)
CALL PLOT(IPAGE,AMAR,NRANGE,5,0,1,465.0,0.0,3.0,0.0)
PRINT 1655
RETURN
```

```
C
1655 FORMAT(1H1)
END
```

APPENDIX E
AVERAGE WORKING LEVELS

determined by:

1. Mining company records based upon area air sampling and exposure time studies.
2. Continuous personal air sampling using thermoluminescent dosimeters (TLD's).

Grants, New Mexico Region
September, 1968 - December, 1969

AVERAGE WORKING LEVELS

Miner Number 1				Miner Number 2			
Day of Study		Mine Co. Sample	TLD Sample	Day of Study		Mine Co. Sample	TLD Sample
Start	Stop			Start	Stop		
1.	22.	.500		1.	22.	.500	
4.	33.			4.	33.		
22.	37.		.020	22.	37.		.090
23.	53.	.700		23.	53.	.500	
38.	53.		.050	38.	53.		.050
53.	85.			41.	54.		
54.	83.	.400		54.	68.		.390
84.	114.	.500		54.	83.	.500	
85.	116.			54.	83.		
115.	145.	.800		84.	114.	.700	
116.	143.			84.	110.		
146.	173.	.600		110.	131.		
146.	176.			115.	145.	.500	
174.	204.	.500		146.	173.	.200	
176.	200.			174.	204.	.200	
200.	222.			174.	201.		
205.	234.	.600		202.	229.		
235.	265.	.200		204.	215.		.020
245.	266.			205.	234.	.200	
260.	271.		0.000	218.	229.		0.000
266.	295.	.300		230.	257.		
266.	292.			232.	243.		.010
292.	327.			235.	265.	.100	
296.	326.	.200		246.	257.		.110
327.	357.	.400		260.	271.		.030
358.	387.	.300		260.	285.		
388.	418.	.300		266.	295.	.100	
419.	448.	.400		285.	299.		
449.	479.	.200		296.	326.	.200	
				309.	313.		0.000
				327.	357.	.800	
				344.	355.		.430
				358.	387.	.200	
				388.	418.	.600	
				419.	448.	.200	
				449.	479.	.200	

AVERAGE WORKING LEVELS

Miner Number 3				Miner Number 4			
Day of Study		Mine Co.	TLD Sample	Day of Study		Mine Co.	TLD Sample
Start	Stop	Sample		Start	Stop	Sample	
1.	22.	.600		1.	22.	0.000	
8.	32.			5.	33.		
22.	37.		.260	22.	37.		.090
23.	53.	.500		23.	53.	.100	
38.	53.		.040	38.	53.		.050
54.	68.		.030	54.	83.	.100	
54.	83.	.600		57.	75.		
83.	98.			84.	114.	.100	
84.	114.	.900		85.	96.		
115.	145.	.500		115.	145.	.100	
117.	145.			120.	145.		
146.	173.	.500		146.	173.	.100	
147.	173.			146.	173.		
174.	204.	.300		174.	204.	.300	
174.	201.			175.	201.		
203.	229.			204.	231.		
205.	234.	.200		205.	234.	.100	
231.	264.			235.	265.	.100	
235.	265.	.200		238.	263.		
266.	295.	.200		266.	295.	.200	
273.	292.			266.	285.		
293.	327.			296.	326.	.100	
296.	326.	.200		309.	313.		.040
309.	313.		0.000	327.	357.	0.000	
316.	327.		0.000	344.	355.		10.530
327.	357.	.300		358.	387.	.200	
343.	355.			388.	418.	.300	
358.	387.	.200		419.	448.	.100	
388.	418.	.400		449.	479.	.100	
419.	448.	.300					
449.	479.	.300					

AVERAGE WORKING LEVELS

Miner Number 5				Miner Number 6			
Day of Study	Start	Stop	Mine Co. Sample	Day of Study	Start	Stop	Mine Co. Sample
1.	22.		.200	1.	22.		.200
7.	33.			4.	34.		
22.	37.		.020	22.	37.		.020
23.	53.		.100	23.	53.		.200
35.	54.			34.	69.		
54.	68.		.090	38.	53.		.020
54.	83.		.100	54.	68.		0.000
55.	75.			54.	83.		.300
77.	103.			69.	89.		
84.	114.		.200	84.	114.		.300
115.	145.		.100	89.	118.		
117.	145.			115.	145.		.400
146.	173.		.100	118.	146.		.400
147.	173.			146.	173.		.400
174.	204.		.100	147.	174.		.200
174.	201.			174.	204.		.200
202.	229.			202.	216.		
205.	234.		.100	205.	234.		.100
230.	257.			216.	244.		
232.	243.		0.000	218.	229.		.180
235.	265.		.100	232.	243.		.200
237.	263.			235.	265.		.100
246.	257.		.030	246.	257.		.130
265.	285.			251.	286.		
266.	295.		.100	260.	285.		0.000
296.	326.		.100	266.	295.		0.000
309.	313.		0.000	296.	326.		.100
315.	327.			300.	314.		
327.	357.		.100	327.	357.		.100
341.	355.			358.	387.		.200
344.	355.		.020	372.	383.		.450
353.	387.		.100	386.	397.		.750
388.	418.		.100	388.	418.		.100
419.	448.		0.000	391.	419.		
449.	479.		0.000	400.	411.		.540
				414.	425.		.610
				419.	448.		0.000
				428.	432.		.530
				435.	444.		.370
				449.	479.		0.000

AVERAGE WORKING LEVELS

Miner Number 7				Miner Number 8			
Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample
1.	22.	.400		1.	22.	.400	
3.	33.			4.	33.		
22.	37.		.060	22.	37.		1.220
23.	53.	.700		23.	53.	.200	
38.	53.		.860	38.	53.		0.000
53.	81.			54.	83.	.200	
54.	83.	.700		54.	83.		
77.	103.			84.	114.	.200	
84.	114.	.800		85.	96.		
114.	144.			111.	141.		
115.	145.	.500		115.	145.	.300	
144.	172.			141.	173.		
146.	173.	.300		146.	173.	.200	
172.	200.			174.	204.	.400	
174.	204.	.400		174.	202.		
205.	234.	.700		205.	234.	.200	
235.	265.	.600		209.	236.		
246.	257.		.030	235.	265.	.200	
260.	271.		.010	260.	271.		.010
266.	295.	.500		266.	295.	.200	
270.	298.			274.	285.		0.000
296.	326.	.300		296.	326.	.100	
298.	326.			309.	313.		.010
309.	313.		.020	327.	357.	.300	
327.	357.	.300		327.	348.		
341.	354.			344.	355.		.080
358.	387.	.100		358.	387.	.400	
388.	418.	1.800		388.	418.	.800	
419.	448.	.300		419.	448.	.100	
449.	479.	.400		449.	479.	0.000	

AVERAGE WORKING LEVELS

Miner Number 9				Miner Number 10			
Day of Study		Mine Co.	TLD	Day of Study		Mine Co.	TLD
Start	Stop	Sample	Sample	Start	Stop	Sample	Sample
1.	22.	.600		1.	22.	.200	
4.	33.			4.	34.		
22.	37.		.050	22.	37.		.080
23.	53.	.600		23.	53.	.100	
38.	53.		.090	35.	55.		
54.	68.		.260	38.	53.		.150
54.	83.	.500		54.	68.		.070
56.	83.			54.	83.	.200	
83.	98.			84.	114.	.200	
84.	114.	.600		85.	116.		
115.	145.	0.000		115.	145.	.100	
146.	173.	.400		146.	173.	.200	
148.	173.			174.	204.	.200	
174.	204.	.100		181.	194.		
205.	234.	.100		205.	234.	.100	
232.	243.		.060	218.	229.		0.000
235.	265.	0.000		235.	265.	.100	
246.	257.		.060	260.	271.		0.000
254.	263.			266.	295.	.100	
260.	271.		.020	274.	285.		.070
266.	295.	0.000		296.	326.	0.000	
274.	285.		0.000	316.	327.		0.000
288.	299.		0.000	327.	357.	.100	
296.	326.	0.000		354.	387.	.200	
302.	306.		0.000	388.	418.	.300	
309.	313.		0.000	419.	448.	.100	
316.	327.		0.000	449.	479.	0.000	
327.	357.	0.000					
344.	355.		0.000				
358.	387.	0.000					
388.	413.	.200					
419.	448.	0.000					
449.	479.	0.000					

AVERAGE WORKING LEVELS

Miner Number 7				Miner Number 8			
Day of Study Start	Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Stop	Mine Co. Sample	TLD Sample
1.	22.	.400		1.	22.	.400	
3.	33.			4.	33.		
22.	37.		.060	22.	37.		1.220
23.	53.	.700		23.	53.	.200	
38.	53.		.860	38.	53.		0.000
53.	81.			54.	83.	.200	
54.	83.	.700		54.	83.		
77.	103.			84.	114.	.200	
84.	114.	.800		85.	96.		
114.	144.			111.	141.		
115.	145.	.500		115.	145.	.300	
144.	172.			141.	173.		
146.	173.	.300		146.	173.	.200	
172.	200.			174.	204.	.400	
174.	204.	.400		174.	202.		
205.	234.	.700		205.	234.	.200	
235.	265.	.600		209.	236.		
246.	257.		.030	235.	265.	.200	
260.	271.		.010	260.	271.		.010
266.	295.	.500		266.	295.	.200	
270.	298.			274.	285.		0.000
296.	326.	.300		296.	326.	.100	
298.	326.			309.	313.		.010
309.	313.		.020	327.	357.	.300	
327.	357.	.300		327.	348.		
341.	354.			344.	355.		.080
358.	387.	.100		358.	387.	.400	
388.	418.	1.800		388.	418.	.800	
419.	448.	.300		419.	448.	.100	
449.	479.	.400		449.	479.	0.000	

AVERAGE WORKING LEVELS

Miner Number 9				Miner Number 10			
Day of Study		Mine Co.	TLD	Day of Study		Mine Co.	TLD
Start	Stop	Sample	Sample	Start	Stop	Sample	Sample
1.	22.	.600		1.	22.	.200	
4.	33.			4.	34.		
22.	37.		.050	22.	37.		.080
23.	53.	.600		23.	53.	.100	
38.	53.		.090	35.	55.		
54.	68.		.260	38.	53.		.150
54.	83.	.500		54.	68.		.070
56.	83.			54.	83.	.200	
83.	98.			84.	114.	.200	
84.	114.	.600		85.	116.		
115.	145.	0.000		115.	145.	.100	
146.	173.	.400		146.	173.	.200	
148.	173.			174.	204.	.200	
174.	204.	.100		181.	194.		
205.	234.	.100		205.	234.	.100	
232.	243.		.060	218.	229.		0.000
235.	265.	0.000		235.	265.	.100	
246.	257.		.060	260.	271.		0.000
254.	263.			266.	295.	.100	
260.	271.		.020	274.	285.		.070
266.	295.	0.000		296.	326.	0.000	
274.	285.		0.000	316.	327.		0.000
288.	299.		0.000	327.	357.	.100	
296.	326.	0.000		354.	387.	.200	
302.	306.		0.000	388.	418.	.300	
309.	313.		0.000	419.	448.	.100	
316.	327.		0.000	449.	479.	0.000	
327.	357.	0.000					
344.	355.		0.000				
358.	387.	0.000					
388.	413.	.200					
419.	448.	0.000					
449.	479.	0.000					

AVERAGE WORKING LEVELS

Miner Number 11				Miner Number 11			
Day of Study	Stop	Mine Co. Sample	TLD Sample	Day of Study	Stop	Mine Co. Sample	TLD Sample
1.	5.	2.180		175.	180.	.600	
1.	12.		.900	182.	187.	.730	
2.	26.			183.	194.		.100
7.	12.	1.000		183.	193.		
14.	19.	.610		189.	194.	1.580	
15.	26.		.010	196.	201.	1.230	
21.	26.	0.000		197.	208.		.040
26.	39.			197.	208.		
28.	33.	0.000		203.	208.	.590	
29.	40.		0.000	210.	215.	1.160	
35.	40.	0.000		217.	222.	.290	
40.	55.			218.	236.		
42.	47.	0.000		224.	229.	1.580	
43.	54.		0.000	225.	236.		.080
49.	54.	0.000		231.	236.	1.260	
56.	61.	0.000		238.	243.	.660	
57.	68.		0.000	245.	250.	.580	
57.	82.			246.	278.		
63.	68.	0.000		252.	257.	.850	
70.	75.	0.000		259.	264.	.950	
71.	82.		0.000	266.	271.	.500	
77.	82.	0.000		267.	278.		.340
84.	89.	0.000		273.	278.	.470	
85.	96.		0.000	280.	285.	.560	
85.	96.			287.	292.	.590	
91.	96.	0.000		294.	299.	.260	
98.	103.	0.000		295.	306.		0.000
99.	110.		0.000	301.	306.	.170	
105.	110.	0.000		308.	313.	.050	
112.	117.	0.000		309.	320.		0.000
119.	124.	.230		315.	320.	0.000	
126.	131.	.340		322.	327.	0.000	
127.	131.			329.	334.	0.000	
133.	138.	.490		330.	334.		0.000
134.	145.		0.000	336.	341.	0.000	
135.	153.			337.	348.		0.000
140.	145.	.570		343.	348.	0.000	
147.	152.	.590		350.	355.	.230	
154.	159.	.790		351.	362.		0.000
155.	166.		.560	357.	362.	.230	
161.	166.	.810		358.	376.		
168.	173.	.770		364.	369.	1.100	
169.	180.		.240	365.	376.		2.430
				371.	376.	1.360	

AVERAGE WORKING LEVELS

Miner Number 11				Miner Number 12			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
378.	383.	5.380		1.	5.	.100	
379.	390.		2.940	1.	12.		1.030
385.	390.	6.500		3.	36.		
392.	397.	3.310		7.	12.	.520	
393.	404.		1.440	14.	19.	.390	
399.	404.	.530		15.	26.		.440
406.	411.	.760		21.	26.	.110	
413.	418.	.890		28.	33.	.300	
420.	425.	.840		29.	40.		1.580
421.	432.		.010	35.	40.	.240	
427.	432.	.620		42.	47.	1.180	
434.	439.	.490		42.	56.		
441.	446.	.460		49.	54.	.800	
				56.	61.	.280	
				57.	68.		.610
				63.	68.	1.930	
				63.	70.		
				70.	75.	1.390	
				77.	82.	0.000	
				84.	89.	0.000	
				85.	96.		0.000
				91.	96.	0.000	
				98.	103.	.250	
				98.	112.		
				99.	110.		.790
				105.	110.	.160	
				112.	117.	.320	
				116.	133.		
				119.	124.	.580	
				126.	131.	.170	
				133.	138.	.180	
				133.	154.		
				140.	145.	.250	
				147.	152.	.310	
				154.	159.	.350	
				161.	166.	.360	
				168.	173.	.130	
				175.	180.	.280	
				182.	187.	.290	
				189.	194.	.290	
				196.	201.	.040	
				203.	208.	.140	
				205.	232.		

AVERAGE WORKING LEVELS

Miner Number 12				Miner Number 13			
Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample
210.	215.	.140		1.	5.	.380	
217.	222.	.040		1.	12.		.070
224.	229.	.150		6.	32.		
231.	236.	.120		7.	12.	.300	
238.	243.	.100		14.	19.	.160	
245.	250.	.020		15.	26.		.550
245.	280.			21.	26.	.150	
252.	257.	.070		28.	33.	.370	
259.	264.	.030		29.	40.		.260
266.	271.	.210		35.	40.	.330	
273.	278.	.170		42.	47.	.310	
280.	285.	.120		45.	54.		
280.	308.			49.	54.	.370	
287.	292.	.470		56.	61.	.260	
294.	299.	.200		57.	68.		.600
301.	306.	.590		57.	80.		
308.	313.	.310		63.	68.	.470	
308.	329.			70.	75.	.370	
315.	320.	.410		71.	82.		.250
322.	327.	.100		77.	82.	.250	
329.	334.	.240		83.	110.		
336.	341.	.120		84.	89.	.440	
336.	364.			85.	96.		.370
343.	348.	.010		91.	96.	.460	
350.	355.	.100		98.	103.	.180	
357.	362.	.090		105.	110.	.160	
364.	369.	.320		112.	117.	.040	
371.	376.	.530		119.	124.	.220	
371.	385.			126.	131.	.160	
378.	383.	.470		133.	138.	.170	
385.	390.	.190		134.	152.		
392.	397.	.320		140.	145.	.120	
392.	420.			147.	152.	.170	
399.	404.	.820		154.	159.	.120	
406.	411.	.330		155.	166.		.240
413.	418.	.240		161.	166.	0.000	
420.	425.	.370		168.	173.	0.000	
427.	432.	0.000		169.	180.		.030
434.	439.	.420		175.	180.	.200	
441.	446.	.280		182.	187.	0.000	
				182.	194.		
				183.	194.		.040
				189.	194.	0.000	

AVERAGE WORKING LEVELS

Miner Number 13				Miner Number 13			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
195.	209.			391.	408.		
196.	201.	.320		392.	397.	.230	
197.	208.		.090	393.	404.		.120
203.	208.	.210		399.	404.	.130	
209.	236.			406.	411.	.140	
210.	215.	.210		407.	418.		.020
217.	222.	.360		413.	418.	.120	
224.	229.	.420		419.	439.		
225.	236.		.350	420.	425.	.920	
231.	236.	.770		427.	432.	.170	
238.	243.	.590		434.	439.	.320	
244.	279.			435.	446.		.030
245.	250.	.520		441.	446.	.360	
246.	250.		1.030				
252.	257.	.730					
259.	264.	.710					
266.	271.	.020					
273.	278.	.030					
279.	306.						
280.	285.	.010					
287.	292.	0.000					
294.	299.	.060					
295.	306.		.010				
301.	306.	0.000					
307.	334.						
308.	313.	0.000					
309.	320.		0.000				
315.	320.	0.000					
322.	327.	.010					
329.	334.	0.000					
330.	334.		0.000				
335.	362.						
336.	341.	0.000					
337.	348.		0.000				
343.	348.	.110					
350.	355.	.020					
351.	362.		.390				
357.	362.	.080					
363.	390.						
364.	369.	.410					
371.	376.	.350					
378.	383.	.130					
379.	390.		.270				
385.	390.	.250					

AVERAGE WORKING LEVELS

Miner Number 14				Miner Number 14			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
1.	5.	.440		197.	208.		
1.	12.		.470	203.	208.	.170	
7.	12.	.240		210.	215.	2.390	
7.	33.			217.	222.	1.770	
14.	19.	.080		218.	236.		
15.	26.		.050	224.	229.	.920	
21.	26.	.080		231.	236.	1.880	
28.	33.	.080		238.	243.	1.810	
29.	40.		.030	245.	250.	.600	
35.	40.	.070		246.	250.		.070
42.	47.	.140		246.	278.		
43.	54.			252.	257.	.250	
44.	54.	.230		259.	264.	0.000	
56.	61.	.270		266.	271.	1.250	
57.	68.		.040	273.	278.	.560	
57.	60.			280.	285.	.420	
63.	68.	.310		287.	292.	.460	
70.	75.	.260		294.	299.	0.000	
77.	82.	.140		295.	306.		0.000
84.	89.	.130		301.	306.	0.000	
85.	96.		.030	308.	313.	0.000	
85.	112.			309.	320.		0.000
91.	96.	.270		315.	320.	.510	
98.	103.	.670		322.	327.	.510	
99.	110.		.050	329.	334.	.250	
105.	110.	.340		330.	334.		.160
112.	117.	1.090		336.	341.	1.260	
113.	131.			337.	348.		1.400
119.	124.	.090		343.	348.	.930	
126.	131.	.150		350.	355.	.500	
133.	138.	.090		351.	362.		.370
134.	152.			357.	362.	.410	
140.	145.	.160		364.	369.	.550	
147.	152.	.250		365.	376.		.680
154.	159.	1.500		371.	376.	.360	
155.	166.		1.380	372.	390.		
161.	166.	2.010		378.	383.	.440	
168.	173.	1.490		379.	390.		.440
175.	180.	.770		385.	390.	.560	
182.	187.	.250		392.	397.	.240	
183.	194.			393.	404.		.330
189.	194.	.510		393.	418.		
196.	201.	.430		399.	404.	.190	
				406.	411.	.280	

AVERAGE WORKING LEVELS

Miner Number 14				Miner Number 15			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
407.	418.		.690	1.	5.	.130	
413.	418.	.200		1.	12.		.490
420.	425.	.240		5.	36.		
421.	432.		.360	7.	12.	.550	
427.	432.	.210		14.	19.	.390	
434.	439.	.180		15.	26.		.020
435.	446.		.160	21.	26.	.110	
441.	446.	.150		28.	33.	.210	
				29.	40.		.040
				35.	40.	.190	
				42.	47.	1.300	
				44.	57.		
				49.	54.	1.000	
				56.	61.	.410	
				57.	68.		.070
				57.	78.		
				63.	68.	2.170	
				70.	75.	1.510	
				77.	82.	.530	
				83.	99.		
				84.	89.	1.310	
				85.	96.		.010
				91.	96.	1.360	
				98.	103.	.730	
				99.	110.		.350
				105.	110.	.540	
				112.	117.	.740	
				115.	127.		
				119.	124.	.710	
				126.	131.	.140	
				133.	138.	.240	
				135.	155.		
				140.	145.	.250	
				147.	152.	.240	
				154.	159.	.610	
				155.	166.		.020
				161.	166.	.220	
				168.	173.	.190	
				175.	180.	.360	
				182.	187.	.320	
				183.	194.		.360
				189.	194.	.140	
				196.	201.	.030	

AVERAGE WORKING LEVELS

Miner Number 15				Miner Number 15			
Day of Study Start	Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Stop	Mine Co. Sample	TLD Sample
198.	205.			427.	432.	1.620	
203.	208.	.190		434.	439.	1.840	
210.	215.	.480		435.	446.		.240
210.	238.			441.	446.	1.160	
217.	222.	1.330					
224.	229.	1.230					
225.	236.		1.570				
231.	236.	1.280					
238.	243.	1.340					
245.	250.	1.170					
246.	250.		1.320				
252.	257.	1.460					
259.	264.	2.730					
266.	271.	0.000					
267.	278.		0.000				
273.	278.	0.000					
280.	285.	0.000					
281.	292.		0.000				
287.	292.	.560					
294.	299.	.450					
295.	306.		.030				
301.	306.	.450					
308.	313.	.460					
309.	320.		.020				
315.	320.	.350					
322.	327.	.460					
329.	334.	.430					
336.	341.	.230					
337.	348.		0.000				
343.	348.	.180					
350.	355.	.320					
357.	362.	.280					
364.	369.	1.270					
365.	376.		.060				
371.	376.	3.750					
378.	383.	1.750					
379.	390.		.490				
385.	390.	1.600					
392.	397.	1.310					
399.	404.	.740					
406.	411.	.700					
407.	418.		.290				
413.	418.	.790					
420.	425.	1.090					

AVERAGE WORKING LEVELS

Miner Number 16			Miner Number 16			
Day of Study	Stop	Mine Co. Sample	Day of Study	Stop	Mine Co. Sample	TLD Sample
1.	5.	.230	238.	243.	0.000	
7.	12.	.510	245.	250.	.030	
11.	34.		245.	275.		
14.	19.	.120	252.	257.	.010	
21.	26.	0.000	259.	264.	.010	
28.	33.	.370	266.	271.	.050	
35.	40.	.680	273.	278.	.320	
42.	47.	1.110	280.	285.	.370	
44.	51.		280.	305.		
49.	54.	.790	287.	292.	.330	
56.	61.	.550	294.	299.	.170	
58.	78.		301.	306.	.160	
63.	68.	.570	308.	313.	.560	
70.	75.	.380	308.	317.		
77.	82.	.710	315.	320.	.340	
84.	89.	.580	322.	327.	.560	
85.	109.		329.	334.	0.000	
91.	96.	.130	336.	341.	0.000	
98.	103.	.100	338.	359.		
105.	110.	.100	343.	348.	.810	
112.	117.	.110	350.	355.	4.540	
113.	128.		357.	362.	.190	
119.	124.	.330	364.	369.	.400	
126.	131.	.270	364.	387.		
132.	155.		371.	376.	1.630	
133.	138.	.130	373.	383.	.480	
140.	145.	.060	385.	390.	.700	
147.	152.	.440	389.	416.		
154.	159.	.080	392.	397.	.860	
161.	166.	1.540	399.	404.	.610	
168.	173.	.160	406.	411.	.780	
175.	180.	.060	413.	418.	.430	
182.	187.	.020	417.	444.		
188.	192.		420.	425.	.250	
189.	194.	.100	427.	432.	.430	
196.	201.	0.000	434.	439.	.310	
197.	205.		441.	446.	.210	
203.	208.	.130				
210.	215.	.080				
210.	237.					
217.	222.	0.000				
224.	229.	0.000				
231.	236.	.190				

AVERAGE WORKING LEVELS

Miner Number 17				Miner Number 17			
Day of Study	Stop	Mine Co. Sample	TLD Sample	Day of Study	Stop	Mine Co. Sample	TLD Sample
1.	5.	.100		197.	208.		1.170
1.	12.		.360	203.	208.	.170	
7.	12.	.520		210.	215.	.270	
7.	31.			211.	222.		2.630
14.	19.	.390		217.	222.	.850	
15.	26.		.100	224.	229.	1.140	
21.	26.	.110		225.	236.		.800
28.	33.	.180		231.	236.	2.150	
29.	40.		.130	232.	235.		
35.	40.	.170		238.	243.	1.580	
40.	54.			245.	250.	1.340	
42.	47.	1.340		245.	257.		
49.	54.	1.070		252.	257.	1.700	
56.	61.	.270		259.	264.	2.720	
57.	68.		.440	266.	271.	2.600	
60.	82.			273.	278.	.390	
63.	68.	2.200		280.	285.	.280	
70.	75.	1.610		287.	292.	.200	
71.	82.		.330	294.	299.	.170	
77.	82.	.540		295.	306.		.250
84.	89.	1.020		301.	306.	0.000	
85.	96.			308.	313.	0.000	
91.	96.	1.360		309.	320.		0.000
98.	103.	.850		315.	320.	.350	
105.	110.	.560		322.	327.	.460	
112.	117.	.850		329.	334.	.450	
119.	124.	.610		330.	334.		0.000
126.	131.	.180		336.	341.	.270	
133.	138.	.220		337.	348.		.150
134.	153.			343.	348.	.200	
140.	145.	.280		350.	355.	.400	
147.	152.	.280		351.	362.		.200
154.	159.	.660		357.	362.	.200	
155.	166.		.640	364.	369.	.560	
161.	166.	.240		365.	376.		.850
168.	173.	.190		371.	376.	.390	
169.	180.		4.480	378.	383.	.210	
175.	180.	.360		379.	390.		.090
182.	187.	.300		385.	390.	.430	
183.	194.		.450	392.	397.	1.010	
183.	187.			393.	404.		.100
189.	194.	.030		399.	404.	.570	
196.	201.	.190		406.	411.	.180	

AVERAGE WORKING LEVELS

Miner Number 17			Miner Number 18		
Day of Study Start	Stop	Mine Co. Sample	Day of Study Start	Stop	Mine Co. Sample
413.	418.	.250	1.	5.	.220
420.	425.	.480	1.	12.	1.650
427.	432.	.420	6.	33.	
434.	439.	.660	7.	12.	.170
441.	446.	.490	14.	19.	.080
			15.	26.	.130
			21.	26.	.080
			28.	33.	.080
			29.	40.	.100
			35.	40.	.070
			40.	54.	
			42.	47.	.150
			49.	54.	.340
			55.	75.	
			56.	61.	.470
			57.	68.	.240
			63.	68.	.350
			70.	75.	.270
			71.	82.	.350
			77.	82.	.160
			84.	89.	.170
			85.	96.	.350
			85.	110.	
			91.	96.	.270
			98.	103.	.690
			105.	110.	1.370
			111.	131.	
			112.	117.	.740
			119.	124.	.090
			126.	131.	.160
			132.	154.	
			133.	138.	.090
			140.	145.	.110
			147.	152.	.110
			154.	159.	.910
			155.	166.	.610
			161.	166.	1.560
			168.	173.	.980
			169.	180.	.440
			175.	180.	.470
			182.	187.	.210
			182.	193.	
			183.	194.	.840

AVERAGE WORKING LEVELS

Miner Number 18				Miner Number 18			
Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample
189.	194.	.350		392.	397.	1.110	
194.	209.			393.	404.		.330
196.	201.	.320		399.	404.	.230	
203.	208.	.180		406.	411.	.190	
210.	215.	.480		407.	418.		.040
210.	237.			413.	418.	.160	
217.	222.	1.770		420.	425.	.210	
224.	229.	1.220		421.	432.		.070
225.	236.		.770	427.	432.	.110	
231.	236.	1.600		434.	439.	.150	
238.	243.	1.860		441.	446.	.150	
244.	278.						
245.	250.	.730					
246.	250.		1.330				
252.	257.	.680					
259.	264.	1.120					
266.	271.	.840					
267.	278.		.530				
273.	278.	.520					
280.	285.	.390					
281.	292.		.110				
287.	292.	1.930					
294.	299.	.500					
295.	306.		.670				
301.	306.	.710					
308.	313.	.670					
309.	320.		0.000				
315.	320.	.390					
322.	327.	.380					
329.	334.	0.000					
330.	334.		0.000				
336.	341.	0.000					
337.	348.		0.000				
343.	348.	0.000					
350.	355.	.080					
351.	362.		0.000				
357.	362.	.300					
362.	389.						
364.	369.	.340					
365.	376.		.530				
371.	376.	.320					
378.	383.	.470					
379.	390.		.520				
385.	390.	.500					

AVERAGE WORKING LEVELS

Miner Number 19				Miner Number 19			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
1.	5.	.100		203.	208.	.420	
1.	12.		.090	210.	215.	.920	
7.	12.	.410		210.	237.		
8.	33.			217.	222.	.940	
14.	19.	.070		224.	229.	.650	
15.	26.		.120	225.	236.		2.020
21.	26.	.090		231.	236.	1.350	
28.	33.	.260		238.	243.	.080	
29.	40.		.350	245.	250.	0.000	
35.	40.	.110		245.	279.		
42.	47.	.210		252.	257.	0.000	
43.	54.			259.	264.	.080	
49.	54.	.230		266.	271.	.100	
56.	61.	.160		273.	278.	.100	
57.	68.		.450	280.	285.	.130	
57.	82.			280.	293.		
63.	68.	.460		287.	292.	.140	
70.	75.	.390		294.	299.	0.000	
71.	82.		.050	295.	306.		0.000
77.	82.	.170		301.	306.	0.000	
84.	89.	.250		308.	313.	0.000	
85.	96.		.130	309.	320.		0.000
85.	108.			315.	320.	.500	
91.	96.	.290		322.	327.	.800	
98.	103.	.190		329.	334.	.160	
105.	110.	.170		336.	341.	.440	
112.	117.	.140		343.	348.	.620	
119.	124.	.220		350.	355.	.660	
119.	132.			357.	362.	.490	
126.	131.	.250		364.	369.	1.020	
133.	138.	.810		371.	376.	2.240	
140.	145.	.110		378.	383.	.340	
141.	153.			385.	390.	.630	
147.	152.	.240		392.	397.	2.400	
154.	159.	.410		399.	404.	.550	
161.	166.	.480		406.	411.	.410	
168.	173.	.740		413.	418.	.250	
175.	180.	.730		420.	425.	.480	
182.	187.	.670		427.	432.	.840	
182.	195.			434.	439.	.480	
189.	194.	.700		441.	446.	.520	
196.	201.	.640					
196.	209.						

AVERAGE WORKING LEVELS

Miner Number 20				Miner Number 20			
Day of Study	Mine	TLD	Day of Study	Mine	TLD		
Start Stop	Co. Sample	Sample	Start Stop	Co. Sample	Sample		
1. 5.	.100		203. 208.	.530			
1. 12.		.060	210. 215.	.920			
1. 26.			211. 222.		.010		
7. 12.	.220		211. 236.				
14. 19.	.070		217. 222.	.960			
15. 26.		.020	224. 229.	.650			
21. 26.	.090		231. 236.	1.140			
28. 33.	.260		238. 243.	.080			
29. 40.		.120	245. 250.	0.000			
35. 40.	.110		246. 278.				
42. 47.	.210		252. 257.	0.000			
43. 54.			259. 264.	.080			
49. 54.	.230		266. 271.	.100			
56. 61.	.170		273. 278.	.100			
57. 68.		.120	280. 285.	.130			
57. 82.			281. 306.				
63. 68.	.460		287. 292.	.140			
70. 75.	.360		294. 299.	.140			
71. 82.		0.000	295. 306.		.060		
77. 82.	.170		301. 306.	.190			
84. 89.	.250		308. 313.	.380			
85. 96.		.010	309. 320.		.020		
85. 110.			315. 320.	0.000			
91. 96.	.290		322. 327.	0.000			
98. 103.	.210		329. 334.	0.000			
105. 110.	.160		336. 341.	0.000			
112. 117.	.140		343. 348.	0.000			
119. 124.	.250		350. 355.	0.000			
126. 131.	.250		357. 362.	0.000			
133. 138.	.810		364. 369.	0.000			
134. 152.			371. 376.	0.000			
140. 145.	.110		378. 383.	0.000			
147. 152.	.340		385. 390.	0.000			
154. 159.	.410		392. 397.	0.000			
161. 166.	.220		399. 404.	0.000			
168. 173.	.740		406. 411.	0.000			
175. 180.	.730		413. 418.	0.000			
182. 187.	.670		420. 425.	0.000			
182. 194.			427. 432.	0.000			
189. 194.	.700		434. 439.	0.000			
196. 201.	.640		441. 446.	0.000			
197. 203.		0.000					
197. 208.							

AVERAGE WORKING LEVELS

Miner Number 21				Miner Number 21			
Day of Study	Mine	TLD	Day of Study	Mine	TLD		
Start	Co. Sample	Sample	Start	Co. Sample	Sample		
1.	5.	2.270	189.	194.	1.430		
1.	12.		194.	209.			
7.	12.	1.050	196.	201.	1.310		
7.	33.		197.	208.		.230	
14.	19.	.580	203.	208.	.580		
15.	26.	.300	210.	215.	1.100		
21.	26.	.840	217.	222.	.890		
28.	33.	1.920	218.	236.			
29.	40.	.140	224.	229.	1.630		
35.	40.	1.730	225.	236.		6.910	
42.	47.	1.140	231.	236.	1.090		
49.	54.	1.240	238.	243.	.690		
56.	61.	.830	244.	278.			
57.	68.	.150	245.	250.	.560		
57.	85.		246.	250.		.680	
63.	68.	1.140	252.	257.	.890		
70.	75.	.870	259.	264.	.960		
71.	82.	.030	266.	271.	.510		
77.	82.	.720	267.	278.		3.820	
84.	89.	1.150	273.	278.	.410		
85.	96.	.030	278.	306.			
87.	117.		280.	285.	.590		
91.	96.	.760	281.	292.		1.270	
98.	103.	.370	287.	292.	.630		
99.	110.	.100	294.	299.	.270		
105.	110.	.160	295.	306.		.830	
112.	117.	.210	301.	306.	.190		
117.	131.		306.	334.			
119.	124.	.300	308.	313.	1.020		
126.	131.	.330	315.	320.	.480		
133.	138.	.570	322.	327.	.410		
140.	145.	.530	329.	334.	.610		
147.	152.	.560	330.	334.		.170	
154.	159.	.790	334.	355.			
155.	166.	.080	336.	341.	.460		
161.	166.	.410	337.	348.		.390	
162.	181.		343.	348.	.470		
168.	173.	.740	350.	355.	.410		
169.	180.	.110	351.	362.		.960	
175.	180.	.600	357.	362.	.230		
181.	194.		362.	390.			
182.	187.	.580	364.	369.	.610		
183.	194.	.160	371.	376.	1.050		
			378.	383.	.660		

AVERAGE WORKING LEVELS

Miner Number 21				Miner Number 22			
Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample
379.	390.		5.140	1.	22.	.300	
385.	390.	4.880		6.	33.		
390.	418.			22.	33.		.040
392.	397.	2.740		23.	53.	.400	
393.	404.		2.090	36.	47.		.020
399.	404.	.500		54.	83.	.700	
406.	411.	.680		83.	118.		
407.	418.		.070	84.	114.	.800	
413.	418.	.790		115.	145.	.400	
420.	425.	.820		146.	173.	.500	
421.	432.		1.460	165.	180.		.200
427.	432.	.320		174.	204.	.400	
434.	439.	.590		205.	234.	.700	
435.	446.		.180	235.	265.	.700	
441.	446.	.460		266.	295.	.200	
				296.	326.	.300	
				327.	357.	.200	
				327.	341.		
				358.	387.	.300	
				369.	390.		
				371.	383.		.720
				386.	397.		.530
				388.	418.	.200	
				390.	418.		
				400.	411.		.510
				414.	425.		.190
				418.	439.		
				419.	448.	.200	
				435.	444.		.120
				449.	479.	1.100	

AVERAGE WORKING LEVELS

Miner Number 23				Miner Number 24			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
1.	22.	.400		1.	22.	.300	
5.	32.			3.	33.		
22.	33.		.050	23.	53.	.300	
23.	53.	.500		33.	54.		
33.	116.			54.	83.	.300	
36.	47.		.350	54.	83.		
54.	83.	.400		84.	114.	.300	
84.	114.	.300		84.	111.		
115.	145.	.300		112.	144.		
145.	172.			115.	145.	.300	
146.	173.	.200		145.	173.		
162.	180.		0.000	146.	173.	.100	
174.	204.	.200		173.	199.		
205.	234.	.200		174.	204.	0.000	
235.	265.	.400		205.	234.	0.000	
243.	326.			235.	265.	0.000	
266.	295.	.200		266.	295.	0.000	
296.	326.	.500		271.	285.		
327.	357.	.300		296.	326.	.100	
358.	387.	.700		299.	319.		
388.	418.	.700		327.	357.	.100	
419.	448.	.500		327.	343.		
449.	479.	.600		358.	387.	.100	
				388.	418.	.100	
				419.	448.	.100	
				449.	479.	0.000	

AVERAGE WORKING LEVELS

Miner Number 25				Miner Number 26			
Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample
1.	22.	0.000		1.	22.	.200	
5.	32.			5.	33.		
22.	33.		.060	22.	33.		.220
23.	53.	.200		23.	53.	.200	
34.	54.			36.	47.		.150
36.	47.		.080	54.	83.	.100	
54.	83.	.300		84.	114.	.200	
56.	82.			115.	145.	.100	
83.	117.			146.	173.	.200	
84.	114.	.200		174.	204.	.200	
115.	145.	.200		205.	234.	.200	
119.	137.			235.	265.	.200	
141.	168.			266.	295.	0.000	
146.	173.	.400		296.	326.	.200	
162.	180.		.030	327.	357.	.100	
174.	204.	.100		358.	387.	.100	
205.	234.	.200		388.	418.	.100	
235.	265.	.100		419.	448.	.100	
239.	261.			449.	479.	.200	
266.	295.	.100					
267.	281.						
296.	326.	0.000					
316.	330.						
327.	341.		.090				
327.	357.	.200					
358.	387.	.100					
371.	383.		.020				
372.	400.						
386.	397.		.130				
388.	418.	.100					
400.	411.		.110				
400.	435.						
414.	425.		.560				
419.	448.	.100					
428.	432.		.170				
435.	444.		.030				
449.	479.	.100					

AVERAGE WORKING LEVELS

Miner Number 27				Miner Number 28			
Day of Study	Stop	Mine Co. Sample	TLD Sample	Day of Study	Stop	Mine Co. Sample	TLD Sample
1.	22.	0.000		1.	22.	0.000	
4.	19.		0.000	5.	33.		
6.	33.			23.	53.	0.000	
22.	33.		.190	33.	111.		
23.	53.	.200		36.	47.		1.170
33.	54.			54.	83.	.300	
54.	83.	.300		84.	114.	.300	
55.	82.			112.	183.		
84.	114.	.300		115.	145.	.500	
89.	118.			146.	173.	.200	
115.	145.	.300		165.	180.		.100
118.	145.			174.	204.	.100	
146.	173.	.400		205.	234.	.100	
165.	180.		.510	235.	265.	.100	
174.	204.	.200		266.	295.	0.000	
205.	234.	.200		296.	326.	0.000	
235.	265.	.100		327.	357.	.100	
266.	295.	.100		358.	387.	.100	
296.	326.	0.000		371.	383.		1.200
305.	322.			386.	397.		.160
327.	357.	.200		388.	418.	0.000	
328.	334.			400.	411.		.460
358.	387.	.100		414.	425.		.150
362.	393.			419.	448.	0.000	
371.	383.		.380	428.	432.		.030
386.	397.		.040	435.	444.		1.500
388.	418.	.100		449.	479.	0.000	
393.	421.						
400.	411.		.210				
414.	425.		.030				
419.	448.	.100					
421.	442.						
428.	432.		.800				
435.	444.		.250				
449.	479.	.100					

AVERAGE WORKING LEVELS

Miner Number 29				Miner Number 30			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
1.	22.	0.000		1.	22.	.300	
5.	33.			4.	33.		
22.	33.		.150	22.	33.		.060
23.	53.	.100		23.	53.	.400	
34.	54.			34.	54.		
36.	47.		.490	36.	47.		.030
40.	54.			54.	83.	.500	
54.	83.	.200		55.	84.		
54.	82.			84.	114.	.600	
82.	117.			84.	117.		
84.	114.	.300		115.	145.	.500	
115.	145.	0.000		118.	145.		
117.	145.			146.	173.	.500	
145.	173.			158.	180.		.050
146.	173.	.100		174.	204.	.600	
162.	180.		.440	205.	234.	.600	
174.	204.	0.000		235.	265.	.600	
205.	234.	0.000		244.	266.		
229.	257.			266.	295.	.400	
235.	265.	0.000		296.	326.	.400	
264.	278.			327.	357.	.200	
266.	295.	0.000		358.	387.	.100	
296.	326.	0.000		358.	392.		
327.	357.	0.000		371.	383.		.090
358.	387.	0.000		386.	397.		.210
388.	418.	0.000		388.	418.	.800	
419.	448.	0.000		394.	449.		
449.	479.	0.000		400.	411.		.450
				414.	425.		1.500
				419.	448.	.300	
				422.	442.		
				428.	432.		1.190
				435.	446.		1.760
				449.	479.	.400	

AVERAGE WORKING LEVELS

Miner Number 31				Miner Number 32			
Day of Study Start	Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Stop	Mine Co. Sample	TLD Sample
1.	22.	.300		1.	5.	.720	
9.	33.			1.	12.		.160
22.	33.		.390	6.	33.		
23.	53.	.300		7.	12.	.560	
35.	111.			14.	19.	0.000	
40.	56.			15.	26.		.980
54.	83.	.300		21.	26.	.370	
56.	84.			28.	33.	.470	
84.	114.	.300		29.	40.		.080
84.	112.			35.	40.	.460	
112.	133.			40.	54.		
115.	145.	.800		42.	47.	.130	
116.	172.			49.	54.	.590	
146.	173.	.300		54.	82.		
174.	204.	0.000		56.	61.	.330	
182.	196.			57.	68.		.050
196.	210.			63.	68.	.070	
205.	234.	.200		70.	75.	.240	
210.	238.			71.	82.		.010
235.	265.	.200		77.	82.	.150	
245.	262.			82.	110.		
266.	295.	0.000		84.	89.	.010	
266.	325.			85.	96.		.020
296.	326.	.300		91.	96.	.220	
327.	357.	.200		98.	103.	.330	
350.	390.			99.	110.		.040
358.	387.	.200		105.	110.	.270	
371.	383.		.130	110.	131.		
386.	397.		.140	112.	117.	1.490	
388.	418.	.100		119.	124.	.450	
400.	411.		.010	126.	131.	.170	
414.	425.		.040	133.	138.	.120	
419.	448.	0.000		140.	145.	.030	
421.	442.			147.	152.	8.030	
435.	444.		.190	154.	159.	.700	
449.	479.	0.000		155.	166.		.280
				161.	166.	.170	
				168.	173.	.450	
				169.	180.		.070
				175.	180.	.380	
				180.	194.		
				182.	187.	.650	
				183.	194.		0.000

AVERAGE WORKING LEVELS

Miner Number 32				Miner Number 32			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
189.	194.	.470		392.	397.	.780	
194.	208.			393.	404.		.740
196.	201.	.350		399.	404.	.770	
197.	208.		.110	406.	411.	1.280	
203.	208.	.440		413.	418.	1.570	
208.	236.			418.	439.		
210.	215.	.670		420.	425.	2.120	
217.	222.	.390		427.	432.	1.760	
224.	229.	.460		434.	439.	.580	
225.	236.		2.960	441.	446.	.580	
231.	236.	2.400					
238.	243.	.430					
243.	278.						
245.	250.	.640					
246.	250.		1.280				
252.	257.	1.170					
253.	264.		0.000				
259.	264.	.840					
266.	271.	.770					
273.	278.	.630					
278.	306.						
280.	285.	3.180					
287.	292.	2.410					
294.	299.	0.000					
295.	306.		0.000				
301.	306.	0.000					
306.	334.						
308.	313.	.210					
309.	320.		.010				
315.	320.	.610					
322.	327.	1.010					
329.	334.	.570					
334.	362.						
336.	341.	0.000					
337.	348.		.010				
343.	348.	.340					
350.	355.	.270					
357.	362.	.360					
362.	390.						
364.	369.	.370					
371.	376.	.410					
378.	383.	.960					
385.	390.	.630					
390.	418.						

AVERAGE WORKING LEVELS

Miner Number 33				Miner Number 33			
Day of Study Start	Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Stop	Mine Co. Sample	TLD Sample
1.	5.	1.510		203.	208.	0.000	
1.	12.		.410	210.	215.	0.000	
5.	18.			211.	222.		0.000
7.	12.	1.340		217.	222.	0.000	
14.	19.	.830		218.	236.		
15.	26.		.070	224.	229.	0.000	
21.	26.	0.000		225.	236.		0.000
28.	33.	0.000		231.	236.	0.000	
35.	40.	0.000		238.	243.	.100	
40.	54.			245.	250.	.420	
42.	47.	.500		246.	250.		.970
49.	54.	.490		252.	257.	.590	
54.	82.			259.	264.	.430	
56.	61.	.410		266.	271.	.320	
57.	68.		.040	267.	278.		.240
63.	68.	.400		273.	278.	.210	
70.	75.	.700		278.	306.		
77.	82.	.380		280.	285.	1.750	
84.	89.	2.370		287.	292.	2.410	
85.	96.		.010	294.	299.	.370	
88.	110.			295.	306.		.010
91.	96.	.770		301.	306.	.050	
98.	103.	.410		306.	334.		
99.	110.		.010	308.	313.	.470	
105.	110.	.300		309.	320.		.030
112.	117.	.570		315.	320.	.820	
117.	131.			322.	327.	.610	
119.	124.	.420		329.	334.	.810	
126.	131.	.390		334.	348.		
133.	138.	.460		336.	341.	.540	
140.	145.	.320		337.	348.		.010
147.	152.	.340		343.	348.	.730	
154.	159.	.810		350.	355.	0.000	
155.	166.		.480	357.	362.	0.000	
161.	166.	.870		362.	390.		
168.	173.	.760		364.	369.	.840	
169.	180.		.700	365.	376.		1.410
175.	180.	.450		371.	376.	1.650	
182.	187.	0.000		378.	383.	.530	
183.	194.		0.000	379.	390.		1.470
189.	194.	0.000		385.	390.	.520	
196.	201.	0.000		390.	411.		
197.	208.		0.000	392.	397.	.630	
				393.	404.		2.110

AVERAGE WORKING LEVELS

Miner Number 33				Miner Number 34			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
399.	404.	.740		1.	5.	.840	
406.	411.	.570		1.	12.		.130
413.	418.	1.090		6.	33.		
420.	425.	.670		7.	12.	5.610	
427.	432.	1.270		14.	19.	0.000	
434.	439.	.250		15.	26.		3.660
441.	446.	.250		21.	26.	0.000	
				28.	33.	.790	
				29.	40.		.010
				35.	40.	.640	
				41.	54.		
				42.	47.	.750	
				49.	54.	.500	
				55.	82.		
				56.	61.	.900	
				57.	68.		.070
				63.	68.	.660	
				70.	75.	.570	
				71.	82.		0.000
				77.	82.	.490	
				82.	110.		
				84.	89.	1.570	
				85.	96.		.020
				91.	96.	.490	
				98.	103.	.630	
				99.	110.		0.000
				105.	110.	.860	
				112.	117.	.410	
				118.	131.		
				119.	124.	.660	
				126.	131.	1.060	
				126.	131.	1.060	
				133.	138.	.610	
				133.	138.	.610	
				140.	145.	.420	
				147.	152.	.480	
				154.	159.	.410	
				155.	166.		.530
				161.	166.	.840	
				168.	173.	.860	
				169.	180.		.800
				175.	180.	.490	
				180.	194.		

AVERAGE WORKING LEVELS

Miner Number 34				Miner Number 34			
Day of Study	Day of Study	Mine Co. Sample	TLD Sample	Day of Study	Day of Study	Mine Co. Sample	TLD Sample
Start	Stop			Start	Stop		
182.	187.	.850		390.	418.	.110	
189.	194.	.480		392.	397.		.110
195.	208.			393.	404.	.490	
196.	201.	1.070		399.	404.	.520	
197.	208.		1.260	406.	411.	.460	
203.	208.	.910		413.	418.		
208.	236.			418.	439.	.390	
210.	215.	.030		420.	425.	0.000	
211.	222.		.010	427.	432.	.090	
217.	222.	0.000		434.	439.		.220
224.	229.	0.000		435.	446.	.250	
225.	236.		.270	441.	446.		
231.	236.	0.000					
238.	243.	0.000					
243.	278.						
245.	250.	0.000					
252.	257.	0.000					
259.	264.	.410					
266.	271.	.380					
273.	278.	.490					
278.	306.						
280.	285.	.130					
287.	292.	.030					
294.	299.	0.000					
301.	306.	0.000					
306.	334.						
308.	313.	0.000					
309.	320.		0.000				
315.	320.	.050					
322.	327.	.610					
329.	334.	1.520					
330.	334.		0.000				
334.	362.						
336.	341.	.500					
337.	348.		0.000				
343.	348.	0.000					
350.	355.	0.000					
351.	362.		0.000				
357.	362.	.380					
362.	390.						
364.	369.	.550					
371.	376.	0.000					
378.	383.	0.000					
385.	390.	0.000					

AVERAGE WORKING LEVELS

Miner Number 35				Miner Number 35			
Day of Study Start	Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Stop	Mine Co. Sample	TLD Sample
1.	5.	.790		210.	215.	.570	
1.	12.		.270	212.	240.		
2.	37.			217.	222.	.370	
7.	12.	.370		224.	229.	.510	
14.	19.	.390		225.	236.		3.480
15.	26.		.260	231.	236.	1.980	
21.	26.	.140		238.	243.	.490	
28.	33.	.720		240.	275.		
29.	40.		.020	245.	250.	.450	
35.	40.	.090		246.	250.		12.990
37.	51.			252.	257.	.650	
42.	47.	.200		259.	264.	1.030	
49.	54.	.290		266.	271.	2.200	
56.	61.	.300		273.	278.	.590	
57.	68.		.060	280.	285.	0.000	
58.	86.			281.	292.		0.000
63.	68.	.320		287.	292.	0.000	
70.	75.	.130		294.	299.	0.000	
71.	82.		0.000	295.	306.		0.000
77.	82.	.080		301.	306.	0.000	
84.	89.	.180		308.	313.	.200	
86.	114.			309.	320.		0.000
91.	96.	.250		312.	338.		
98.	103.	.490		315.	320.	.630	
99.	110.		.140	322.	327.	1.010	
105.	110.	.270		329.	334.	.540	
112.	117.	.800		336.	341.	.410	
115.	128.			337.	348.		1.260
119.	124.	1.260		338.	366.		
126.	131.	.160		343.	348.	.430	
133.	138.	.500		350.	355.	.650	
140.	145.	.630		351.	362.		.800
147.	152.	5.970		357.	362.	.350	
154.	159.	.680		364.	369.	.390	
155.	166.		.260	365.	376.		.590
161.	166.	.460		366.	394.		
168.	173.	.470		371.	376.	.330	
175.	180.	.560		378.	383.	.860	
182.	187.	.520		379.	390.		.360
183.	198.			385.	390.	.720	
189.	194.	.370		392.	397.	1.470	
196.	201.	.460		393.	404.		.940
203.	208.	.470		394.	422.		
				399.	404.	1.280	

AVERAGE WORKING LEVELS

Miner Number 35				Miner Number 36			
Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Day of Study Stop	Mine Co. Sample	TLD Sample
406.	411.	1.270		1.	5.	.690	
407.	418.		.230	1.	12.		.180
413.	418.	1.570		7.	12.	.250	
420.	425.	1.720		14.	19.	.180	
421.	432.		.090	15.	26.		.020
422.	443.			19.	40.		
427.	432.	1.110		21.	26.	.310	
434.	439.	.470		28.	33.	.140	
435.	446.		.450	29.	40.		0.000
441.	446.	.660		35.	40.	.290	
				42.	47.	1.020	
				43.	54.		
				49.	54.	1.310	
				55.	80.		
				56.	61.	.900	
				57.	68.		.880
				63.	68.	1.260	
				70.	75.	.420	
				71.	82.		.750
				77.	82.	.310	
				81.	112.		
				84.	89.	.410	
				85.	96.		.120
				91.	96.	.550	
				98.	103.	.450	
				99.	110.		.310
				105.	110.	.560	
				111.	154.		
				112.	117.	.410	
				119.	124.	.460	
				126.	131.	.470	
				133.	138.	.500	
				140.	145.	.190	
				147.	152.	.240	
				154.	159.	.440	
				155.	166.		.900
				161.	166.	.320	
				168.	173.	.160	
				169.	180.		.160
				175.	180.	.170	
				182.	187.	.300	
				183.	195.		
				189.	194.	1.560	

AVERAGE WORKING LEVELS

Miner Number 36				Miner Number 36			
Day of Study	Mine	TLD		Day of Study	Mine	TLD	
Start Stop	Co. Sample	Sample		Start Stop	Co. Sample	Sample	
196. 201.	.890			393. 418.	.480		
197. 215.				399. 404.	.240		
203. 208.	1.040			406. 411.		.590	
210. 215.	.580			407. 418.	.160		
211. 222.		.070		413. 418.	.110		
217. 222.	.370			420. 425.			
218. 236.				420. 446.		.880	
224. 229.	.460			421. 432.	.590		
225. 236.		.420		427. 432.	.250		
231. 236.	.480			434. 439.		.610	
238. 243.	.140			435. 446.	.110		
245. 250.	.250			441. 446.			
246. 250.		.150					
246. 278.							
252. 257.	.210						
259. 264.	.430						
266. 271.	1.620						
273. 278.	.460						
280. 285.	.320						
281. 292.		0.000					
281. 306.							
287. 292.	1.250						
294. 299.	.820						
301. 306.	.360						
308. 313.	.370						
309. 334.							
315. 320.	.440						
322. 327.	.550						
329. 334.	.760						
336. 341.	.200						
337. 348.		.090					
337. 362.							
343. 348.	.140						
350. 355.	0.000						
357. 362.	0.000						
364. 369.	.450						
365. 376.		.030					
365. 390.							
371. 376.	1.390						
378. 383.	.280						
379. 390.		.460					
385. 390.	.090						
392. 397.	.140						
393. 404.		.430					

AVERAGE WORKING LEVELS

Miner Number 36			Miner Number 37			
Day of Study Start	Stop	Mine Co. Sample	Day of Study Start	Stop	Mine Co. Sample	TLD Sample
434.	439.	0.000	1.	5.	.440	
441.	446.	0.000	1.	12.		.250
			5.	33.		
			7.	12.	.260	
			14.	19.	.180	
			15.	26.		.020
			21.	26.	.300	
			23.	33.	.270	
			29.	40.		.010
			35.	40.	.310	
			40.	54.		
			42.	47.	.950	
			49.	54.	1.320	
			54.	82.		
			56.	61.	.300	
			57.	68.		.030
			63.	68.	.530	
			70.	75.	.440	
			71.	82.		.010
			77.	82.	.350	
			84.	89.	.470	
			85.	96.		0.000
			89.	110.		
			91.	96.	.660	
			98.	103.	.540	
			105.	110.	.620	
			112.	117.	.440	
			117.	128.		
			119.	124.	.580	
			126.	131.	.470	
			133.	138.	.500	
			138.	152.		
			140.	145.	.140	
			147.	152.	.170	
			154.	159.	.270	
			155.	166.		.280
			161.	166.	.380	
			168.	173.	.110	
			175.	180.	.380	
			180.	194.		
			182.	187.	.480	
			189.	194.	.800	
			196.	201.	.280	

AVERAGE WORKING LEVELS

Miner Number 37				Miner Number 38			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
196.	210.			1.	5.	.730	
197.	208.		.220	1.	12.		.460
203.	208.	.200		5.	33.		
210.	215.	.280		7.	12.	.270	
215.	236.			14.	19.	.340	1.100
217.	222.	.420		15.	26.	.230	
224.	229.	.270		21.	26.	.470	
225.	236.		1.360	28.	33.		.480
231.	236.	.490		29.	40.	.210	
238.	243.	.820		35.	40.		
243.	278.			40.	54.		
245.	250.	2.280		42.	47.	.170	
246.	250.		1.200	49.	54.	.620	
252.	257.	.520		54.	80.		
259.	264.	.380		56.	61.	.320	
266.	271.	.340		57.	68.		.100
267.	278.		.880	63.	68.	.140	
273.	278.	0.000		70.	75.	.230	
278.	313.			71.	82.		.090
280.	285.	.490		77.	82.	.150	
287.	292.	2.000		81.	110.		
294.	299.	.820		84.	89.	.260	
295.	306.		.150	85.	96.		.250
301.	306.	1.240		91.	96.	.230	
308.	313.	1.720		98.	103.	.350	
309.	320.		.010	99.	110.		.610
313.	320.			105.	110.	.470	
315.	320.	.820		112.	117.	1.450	
322.	327.	.620		119.	124.	.880	
329.	334.	.530		126.	131.	.140	
336.	341.	0.000		133.	138.	.150	
343.	348.	0.000		140.	145.	.120	
350.	355.	0.000		147.	152.	8.000	
357.	362.	0.000		154.	159.	.630	
364.	369.	0.000		155.	166.		.110
371.	376.	0.000		161.	166.	.160	
378.	383.	0.000		168.	173.	.460	
385.	390.	0.000		169.	180.		.130
392.	397.	0.000		175.	180.	.550	
399.	404.	0.000		180.	194.		
406.	411.	0.000		182.	187.	.660	
413.	418.	0.000		189.	194.	.410	
420.	425.	0.000		194.	210.		
427.	432.	0.000					

AVERAGE WORKING LEVELS

Miner Number 38				Miner Number 39			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
196.	201.	.480		1.	5.	.450	
203.	208.	.410		3.	33.		
208.	215.			7.	12.	1.630	
210.	215.	.680		14.	19.	6.880	
217.	222.	.300		21.	26.	3.670	
224.	229.	1.060		28.	33.	.710	
225.	236.		2.680	35.	40.	.790	
231.	236.	2.410		40.	54.		
238.	243.	.440		42.	47.	.260	
245.	250.	.640		49.	54.	.700	
252.	257.	1.150		54.	68.		
259.	264.	1.040		56.	61.	.960	
266.	271.	0.000		63.	68.	1.250	
267.	278.		0.000	70.	75.	.310	
273.	278.	0.000		77.	82.	.100	
280.	285.	0.000		84.	89.	.410	
281.	292.		0.000	89.	110.		
287.	292.	2.580		91.	96.	.290	
294.	299.	.250		98.	103.	.560	
301.	306.	.420		105.	110.	.080	
308.	313.	.300		112.	117.	.190	
309.	320.		.010	119.	124.	0.000	
315.	320.	.400		124.	152.		
322.	327.	.460		126.	131.	.380	
329.	334.	.470		133.	138.	2.020	
336.	341.	.370		140.	145.	.410	
343.	348.	.480		147.	152.	1.130	
350.	355.	.630		154.	159.	2.350	
357.	362.	.380		161.	166.	3.090	
364.	369.	.430		168.	173.	.640	
371.	376.	.410		175.	180.	.530	
378.	383.	.420		180.	194.		
385.	390.	.570		182.	187.	.190	
392.	397.	.440		189.	194.	.780	
399.	404.	.420		196.	201.	.490	
406.	411.	.460		197.	215.		
413.	418.	.320		203.	208.	.100	
420.	425.	.500		210.	215.	.090	
427.	432.	.560		215.	236.		
434.	439.	.380		217.	222.	.570	
441.	446.	.200		224.	229.	.470	
				231.	236.	.280	
				236.	278.		

AVERAGE WORKING LEVELS

Miner Number 39				Miner Number 40			
Day of Study		Mine	TLD	Day of Study		Mine	TLD
Start	Stop	Co. Sample	Sample	Start	Stop	Co. Sample	Sample
238.	243.	.320		1.	5.	.420	
245.	250.	.410		1.	12.		.450
252.	257.	.340		3.	26.		
259.	264.	.520		7.	12.	.190	
266.	271.	2.180		14.	19.	.190	
273.	278.	.100		15.	26.		.250
278.	309.			21.	26.	.420	
280.	285.	.090		28.	33.	.270	
287.	292.	.100		29.	40.		1.180
294.	299.	.310		35.	40.	.270	
301.	306.	.010		42.	47.	1.000	
308.	313.	.040		49.	54.	1.390	
309.	334.			56.	61.	.280	
315.	320.	.150		57.	68.		.380
322.	327.	.040		63.	68.	.500	
329.	334.	.110		70.	75.	.380	
336.	341.	.090		71.	82.		.040
343.	348.	.100		77.	82.	.230	
343.	355.			84.	89.	.460	
350.	355.	.490		85.	96.		.680
357.	362.	.770		91.	96.	.480	
362.	379.			98.	103.	.400	
364.	369.	.380		99.	110.		.770
371.	376.	.250		105.	110.	.350	
378.	383.	.160		112.	117.	.410	
385.	390.	0.000		119.	124.	.530	
392.	397.	0.000		126.	131.	.470	
398.	435.			133.	138.	.480	
399.	404.	.320		140.	145.	.140	
406.	411.	.780		147.	152.	.100	
413.	418.	.900		154.	159.	.300	
420.	425.	.280		155.	166.		96.910
427.	432.	.230		161.	166.	.260	
434.	439.	.400		168.	173.	.070	
441.	446.	1.990		175.	180.	.460	
				182.	187.	.180	
				183.	194.		.300
				189.	194.	.290	
				196.	201.	.310	
				203.	208.	.050	
				210.	215.	.100	
				217.	222.	0.000	
				224.	229.	0.000	

AVERAGE WORKING LEVELS

Miner Number 40			Miner Number 41				
Day of Study	Mine	TLD	Day of Study	Mine	TLD		
Start	Co. Sample	Sample	Start	Co. Sample	Sample		
225.	236.		1.	5.	.940		
231.	236.	0.000	1.	12.		.250	
238.	243.	0.000	7.	12.	.740		
245.	250.	.210	8.	32.			
246.	250.		14.	19.	.670		
252.	257.	.550	21.	26.	1.270		
259.	264.	.240	28.	33.	.850		
266.	271.	.740	29.	40.		.020	
273.	278.	1.780	35.	40.	.690		
280.	285.	.200	40.	53.			
287.	292.	0.000	42.	47.	1.060		
294.	299.	0.000	49.	54.	1.290		
301.	306.	0.000	54.	81.			
308.	313.	0.000	56.	61.	1.060		
315.	320.	0.000	63.	68.	.980		
322.	327.	0.000	70.	75.	.080		
329.	334.	0.000	77.	82.	.110		
336.	341.	0.000	82.	112.			
343.	348.	0.000	84.	89.	.280		
350.	355.	0.000	91.	96.	.210		
357.	362.	0.000	98.	103.	.090		
364.	369.	0.000	99.	110.		0.000	
371.	376.	0.000	105.	110.	.160		
378.	383.	0.000	112.	117.	.140		
385.	390.	0.000	117.	130.			
392.	397.	0.000	119.	124.	.130		
399.	404.	0.000	126.	131.	.280		
406.	411.	0.000	133.	138.	.150		
413.	418.	0.000	140.	145.	0.000		
420.	425.	0.000	147.	152.	0.000		
427.	432.	0.000	154.	159.	.250		
434.	439.	0.000	159.	179.			
441.	446.	0.000	161.	166.	.010		
			168.	173.	.070		
			169.	180.		.350	
			175.	180.	1.050		
			180.	193.			
			182.	187.	.400		
			189.	194.	.300		
			194.	207.			
			196.	201.	.050		
			203.	208.	.070		
			208.	235.			

AVERAGE WORKING LEVELS

Miner Number 41				Miner Number 41			
Day of Study Start	Stop	Mine Co. Sample	TLD Sample	Day of Study Start	Stop	Mine Co. Sample	TLD Sample
210.	215.	.160		420.	425.	.460	
217.	222.	.100		427.	432.	.700	
224.	229.	.070		434.	439.	.430	
225.	236.		.420	435.	446.		.020
231.	236.	.160		441.	446.	.150	
238.	243.	.210					
243.	277.						
245.	250.	.170					
252.	257.	.100					
259.	264.	0.000					
266.	271.	.390					
273.	278.	.120					
278.	305.						
280.	285.	.380					
287.	292.	.600					
294.	299.	.530					
301.	306.	.410					
306.	334.						
308.	313.	0.000					
309.	320.		0.000				
315.	320.	0.000					
322.	327.	0.000					
329.	334.	.830					
330.	334.		0.000				
336.	341.	.570					
341.	361.						
343.	348.	.370					
350.	355.	.720					
351.	362.		.310				
357.	362.	.360					
362.	389.						
364.	369.	.700					
365.	376.		.460				
371.	376.	.410					
378.	383.	.420					
379.	390.		.300				
385.	390.	.550					
390.	417.						
392.	397.	.520					
393.	404.		.050				
399.	404.	.340					
406.	411.	.480					
413.	418.	0.000					
418.	438.						

APPENDIX F

Ra-D AND Ra-F SPECIFIC ACTIVITIES OBSERVED IN WHISKER AND BLOOD SAMPLES
FROM URANIUM MINERS AND UNEXPOSED CONTROL SUBJECTS

Grants, New Mexico Region

September, 1968 - December, 1969

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	START	STOP	PCI RA-D/G WHISKERS	PCI RA-F/G WHISKERS	PCI RA-D/G BLOOD	PCI RA-F/G BLOOD
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MINER'S NUMBER = 1

	193.				.018	.095
	223.				.041	.153
	261.				.018	.144
4.	33.	2.662	0.000			
53.	85.	2.032	0.000			
85.	116.	2.198	0.000			
116.	143.	.923	0.000			
146.	176.	7.374	0.000			
176.	200.	2.784	2.054			
200.	222.	5.964	0.000			
245.	266.	1.937	5.622			
266.	292.	1.752	2.514			
292.	327.	5.554	4.820			

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 2

	194.			.014	.009
	222.			.108	.135
	260.			.108	.009
4.	33.	5.252	0.000		
41.	54.	7.703	36.937		
54.	83.	8.216	0.000		
84.	110.	1.140	10.108		
110.	131.	1.829	0.000		
174.	201.	1.653	0.000		
202.	229.	1.802	3.829		
230.	257.	.545	8.387		
260.	285.	1.189	10.568		
285.	299.	1.252	0.000		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 3

8.	32.	9.748	0.000
36.	65.	5.923	1048.419
83.	98.	10.027	1.059
117.	145.	10.194	9.086
147.	173.	12.284	0.000
174.	201.	3.527	1.248
203.	229.	2.712	.203
231.	264.	2.865	4.257
273.	292.	2.815	0.000
293.	327.	4.338	3.626
343.	355.	6.865	0.000

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 4

	212.		0.000	1.829
	223.		.059	0.000
	261.		.014	.194
5.	33.	.387		.806
36.	54.	0.000	268.491	
57.	75.	.946	6.568	
85.	96.	.644	1.441	
120.	145.	.207	2.437	
146.	173.	.207	12.162	
175.	201.	.685	2.779	
204.	231.	.770	4.464	
238.	263.	1.077	0.000	
266.	285.	.887	2.604	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 5

7.	33.	.721	1.365
35.	54.	.604	7.955
55.	75.	2.509	0.000
77.	103.	.009	.117
117.	145.	.901	0.000
147.	173.	.829	.347
174.	201.	1.450	0.000
202.	229.	.775	3.865
230.	257.	.734	6.320
237.	263.	2.068	4.176
265.	285.	.730	0.000
315.	327.	1.410	.973
341.	355.	.658	1.892

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 6

	218.		.023	.252
	261.		0.000	.009
	412.		.045	.140
4.	34.	.716	0.000	
34.	69.	.640	28.748	
69.	89.	.284	89.721	
89.	118.	.527	4.883	
118.	146.	1.158	0.000	
147.	174.	1.419	0.000	
174.	202.	1.419	0.000	
202.	216.	1.761	0.000	
216.	244.	.590	12.797	
251.	286.	.721	26.685	
286.	300.	1.599	0.000	
300.	314.	2.518	27.387	
363.	391.	1.212	1.293	
391.	419.	1.113	0.000	
419.	439.	1.779	0.000	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 7

3.	33.	2.793	0.000
53.	81.	1.928	8.194
77.	103.	1.329	1.077
114.	144.	.887	2.644
144.	172.	1.126	0.000
172.	200.	3.144	1.437
270.	298.	1.455	3.324
298.	326.	6.311	0.000
341.	354.	2.995	.883

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 8

	194.			.090	3.293
	219.			.135	.023
	262.			.126	0.000
4.	33.	23.730	0.000		
54.	83.	29.104	30.518		
85.	96.	16.401	3.532		
111.	141.	7.712	0.000		
141.	173.	13.113	0.000		
174.	202.	16.950	12.950		
209.	236.	22.743	9.392		
327.	348.	2.315	2.333		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 9

	223.			.387	0.000
4.	33.	2.216	0.000		
56.	83.	1.329	.874		
83.	98.	.716	0.000		
148.	173.	1.113	1.032		
254.	263.	.910	3.126		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 10

	211.			0.000	.144
4.	34.	1.550	0.000		
35.	55.	1.054	36.757		
85.	116.	2.946	0.000		
181.	194.	1.117	12.608		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 11

	234.			.036	.329
	247.			.036	.009
	282.			.041	.315
	376.			.045	.396
2.	26.	5.153	0.000		
26.	39.	2.099	5.662		
40.	55.	0.000	2.631		
57.	82.	.477	0.000		
85.	96.	.135	2.730		
127.	131.	1.167	3.473		
135.	153.	4.333	0.000		
183.	193.	3.869	0.000		
197.	208.	3.514	0.000		
218.	236.	1.090	0.000		
246.	278.	2.802	0.000		
358.	376.	1.459	0.000		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 12

3.	36.	2.523	0.000
42.	56.	.387	.297
63.	70.	2.045	20.248
98.	112.	2.626	0.000
116.	133.	3.766	0.000
133.	154.	12.432	0.000
205.	232.	.905	0.000
245.	280.	1.221	5.369
280.	308.	1.703	0.000
308.	329.	2.333	.405
336.	364.	1.838	1.203
371.	385.	5.203	.031
392.	420.	7.378	.689

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 13

	232.		.041	0.000
	241.		.036	0.000
	282.		.018	.126
	339.		.045	.545
	369.		.077	.099
	414.		.063	.185
6.	32.	1.113	2.779	
45.	54.	.910	1.059	
57.	80.	1.248	0.000	
83.	110.	1.514	0.000	
116.	130.	1.514	0.000	
134.	152.	.203	6.716	
182.	194.	3.248	4.315	
195.	209.	.869	2.270	
209.	236.	.829	5.342	
244.	279.	.356	.874	
279.	306.	.545	1.550	
307.	334.	.131	.518	
335.	362.	3.995	0.000	
363.	390.	.257	.730	
391.	408.	.450	1.023	
419.	439.	.545	.892	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 14

	239.		.077	0.000
7.	33.	.847		
43.	54.	.685		5.266
57.	60.	.595		3.216
85.	112.	.059		3.459
113.	131.	1.027		.941
134.	152.	1.027		.941
183.	194.	5.036		0.000
197.	208.	1.185		5.946
218.	236.	.869		6.856
246.	278.	1.032		2.284
372.	390.	0.000		5.590
393.	418.	.626		2.505

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY START	STUDY STOP	PCI RA-D/G WHISKERS	PCI RA-F/G WHISKERS	PCI RA-D/G BLOOD	PCI RA-F/G BLOOD
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MINER'S NUMBER = 15

	232.			.032	1.315
5.	36.	5.432	0.000		
44.	57.	7.284	0.000		
57.	78.	5.910	0.000		
83.	99.	4.707	11.437		
115.	127.	2.766	9.865		
135.	155.	2.797	0.000		
198.	205.	4.459	0.000		
210.	238.	3.450	3.932		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 16

	237.		.032	0.000
	241.		.059	0.000
	283.		.023	.131
	339.		.086	.356
	370.		.072	0.000
	415.		.081	.185
	449.		.081	.158
11.	34.	1.541	0.000	
44.	51.	2.640	3.014	
58.	78.	.725	0.000	
85.	109.	3.000	0.000	
113.	128.	2.856	0.000	
132.	155.	4.239	0.000	
188.	192.	1.676	2.126	
197.	205.	2.009	1.905	
210.	237.	1.081	0.000	
245.	275.	.108	.910	
280.	305.	1.032	.167	
308.	317.	3.793	0.000	
338.	359.	4.748	0.000	
364.	387.	4.212	0.000	
389.	416.	.631	3.563	
417.	444.	3.234	2.905	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 17

	233.			.077	0.000
7.	31.	1.140	0.000		
40.	54.	1.581	1.162		
60.	82.	2.387	1.167		
85.	96.	.847	4.811		
126.	131.	0.000	5.500		
134.	153.	1.878	0.000		
183.	187.	2.811	2.500		
232.	235.	1.788	5.149		
245.	257.	2.635	1.613		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START, STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 18

	239.			.059	0.000
6.	33.	1.545	0.000		
40.	54.	3.167	0.000		
55.	75.	1.225	.171		
85.	110.	2.680	0.000		
111.	131.	.207	1.824		
132.	154.	3.176	13.077		
182.	193.	1.757	7.320		
194.	209.	2.360	1.820		
210.	237.	.887	0.000		
244.	278.	2.847	0.000		
362.	389.	1.185	3.158		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 19

	232.			.045	0.000
8.	33.	.541	0.000		
43.	54.	2.662	1.973		
57.	82.	1.730	3.158		
85.	108.	.613	6.288		
119.	132.	.896	4.703		
141.	153.	1.257	0.000		
182.	195.	.892	5.748		
196.	209.	.396	2.559		
210.	237.	.766	1.955		
245.	279.	1.081	.811		
280.	293.	0.000	.662		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 20

1.	26.	1.167	0.000
43.	54.	2.225	0.000
57.	82.	.401	5.631
85.	110.	.779	3.437
113.	131.	.779	3.437
134.	152.	1.739	19.581
182.	194.	3.392	0.000
197.	208.	1.698	14.203
211.	236.	1.550	9.347
246.	278.	2.928	12.149
281.	306.	3.063	4.162

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	START	STOP	PCI RA-D/G WHISKERS	PCI RA-F/G WHISKERS	PCI RA-D/G BLOOD	PCI RA-F/G BLOOD
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MINER'S NUMBER = 21

	232.				.041	.027
	242.				.045	1.005
	282.				.041	.117
	341.				.090	1.360
7.	33.		4.761	0.000		
57.	85.		6.117	0.000		
87.	117.		2.860	1.518		
117.	131.		1.640	6.752		
162.	181.		1.631	0.000		
181.	194.		3.207	1.581		
194.	209.		2.878	4.491		
218.	236.		3.590	2.505		
244.	278.		1.477	1.491		
278.	306.		1.626	1.275		
306.	334.		1.973	1.977		
334.	355.		5.901	1.649		
362.	390.		2.027	3.878		
390.	418.		2.167	4.014		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 22

199.			.045	.027
228.			.099	0.000
257.			.045	.045
302.			.023	.950
415.			.041	.450
6.	33.	1.356	1.770	
33.	83.	4.739	0.000	
83.	118.	3.486	0.000	
118.	145.	2.437	12.180	
146.	173.	2.712	5.500	
243.	264.	2.617	11.059	
264.	292.	.905	3.392	
292.	327.	1.023	3.252	
327.	341.	2.644	1.982	
369.	390.	2.676	5.577	
390.	418.	2.441	2.901	
418.	439.	1.631	3.554	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 23

	199.			.014	.023
	227.			.077	.131
	256.			.072	.104
5.	32.	3.707	31.757		
33.	116.	1.865	0.000		
145.	172.	12.982	0.000		
243.	326.	7.176	0.000		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 24

3.	33.	1.640	0.000
33.	54.	4.959	0.000
54.	83.	4.284	0.000
84.	111.	5.536	0.000
112.	144.	15.626	0.000
145.	173.	2.428	0.000
173.	199.	1.712	0.000
271.	285.	1.252	3.432
299.	319.	1.482	0.000
327.	343.	1.748	1.446

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 25

192.			0.000	.081
271.			.018	.149
290.			0.000	.090
5. 32.	2.081	5.320		
34. 54.	2.396	6.153		
56. 82.	3.149	0.000		
83. 117.	.514	29.851		
119. 137.	2.297	4.577		
141. 168.	2.194	0.000		
239. 261.	1.577	2.023		
267. 281.	2.356	3.032		
316. 330.	2.640	10.775		
372. 400.	3.378	0.000		
400. 435.	3.613	0.000		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 26

5.	33.	.324	0.000
33.	54.	2.099	0.000
55.	75.	1.739	0.000
83.	103.	.018	40.770
118.	145.	1.649	0.000
146.	180.	.527	0.000

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 27

6.	33.	1.995	1.099
33.	54.	2.869	0.000
55.	82.	2.716	0.000
89.	118.	1.392	0.000
118.	145.	3.707	0.000
146.	173.	0.000	8.595
146.	173.	0.000	8.595
305.	322.	2.550	0.000
328.	334.	6.036	0.000
362.	393.	.820	0.000
393.	421.	2.311	0.000
421.	442.	2.068	.158

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 28

5.	33.	1.333	5.892
33.	111.	3.775	0.000
112.	183.	4.482	0.000

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 29

201.			.387	0.000
233.			.005	0.000
263.			0.000	.194
295.			.050	.054
5.	33.	.811	0.000	
34.	54.	.464	3.248	
40.	54.	0.000	12.284	
54.	82.	1.703	0.000	
82.	117.	0.000	6.468	
117.	145.	1.293	3.338	
145.	173.	.928	1.018	
217.	231.	1.207	15.284	
229.	257.	.297	0.000	
264.	278.	1.473	0.000	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 30

197.			.014	.910
233.			.045	0.000
261.			.095	0.000
284.			.036	.257
408.			.099	.378
4. 33.	3.356	0.000		
34. 54.	3.374	0.000		
55. 84.	4.369	0.000		
84. 117.	1.811	14.243		
118. 145.	3.086	16.446		
146. 173.	4.338	0.000		
244. 266.	5.459	0.000		
266. 301.	4.014	0.000		
301. 327.	6.842	0.000		
358. 392.	2.441	6.658		
394. 449.	4.032	3.117		
422. 442.	5.347	0.000		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 31

198.			.086	.027
232.			.086	.027
256.			.036	.050
284.			.036	.135
9.	33.	0.000	.221	
35.	111.	20.356	0.000	
40.	56.	.860	5.432	
56.	84.	2.423	3.671	
84.	112.	.446	3.171	
112.	133.	1.018	1.077	
116.	172.	2.694	.261	
182.	196.	2.396	0.000	
196.	210.	2.338	.694	
210.	238.	0.000	1.734	
245.	262.	0.000	3.266	
266.	325.	1.559	.171	
350.	390.	2.225	0.000	
392.	417.	3.725	1.995	
421.	442.	2.081	0.000	
198.			.086	.027
232.			.086	.027
256.			.036	.050

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 32

	276.		.036	.288
	345.		.045	.018
	374.		.027	.176
	416.		.081	.171
	431.		.005	.459
6.	33.	1.721	7.802	
40.	54.	1.126	2.991	
54.	82.	.919	1.577	
82.	110.	.919	2.896	
110.	131.	.919	2.896	
180.	194.	3.437	0.000	
194.	208.	3.676	.077	
208.	236.	1.455	1.401	
243.	278.	1.631	.572	
278.	306.	3.194	2.414	
306.	334.	1.604	2.865	
334.	362.	.995	3.320	
362.	390.	2.302	4.189	
390.	418.	2.658	68.770	
418.	439.	2.514	1.257	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 33

	236.		.036	.135
	269.		.054	.108
	338.		.063	.896
	372.		.072	0.000
5.	18.	19.441	0.000	
40.	54.	1.441	10.523	
54.	82.	2.068	1.018	
88.	110.	0.000	13.527	
117.	131.	8.090	0.000	
218.	236.	.775	2.284	
278.	306.	.171	7.113	
306.	334.	3.279	6.315	
334.	348.	10.135	4.797	
362.	390.	1.829	11.995	
390.	411.	3.928	13.446	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 34

	241.			.077	.761
	348.			.149	.036
	317.			.099	.685
	369.			.077	.793
6.	33.	.950	0.000		
41.	54.	4.495	0.000		
55.	82.	3.923	0.000		
82.	110.	2.752	0.000		
118.	131.	1.734	0.000		
180.	194.	.955	0.000		
195.	208.	2.955	0.000		
208.	236.	3.748	0.000		
243.	278.	1.883	0.000		
278.	306.	1.104	.946		
306.	334.	1.252	0.000		
334.	362.	4.581	0.000		
362.	390.	3.527	1.545		
390.	418.	.194	1.221		
418.	439.	1.527	.437		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 35

	240.		.036	.383
	269.		.059	0.000
2.	37.	2.261	0.000	
37.	51.	1.365	0.000	
58.	86.	1.261	0.000	
86.	114.	.491	0.000	
115.	128.	.946	3.986	
183.	198.	2.712	0.000	
198.	215.	2.712	0.000	
212.	240.	1.806	0.000	
240.	275.	.928	1.063	
312.	338.	1.671	.054	
338.	366.	1.964	0.000	
366.	394.	1.207	3.221	
394.	422.	1.793	2.946	
422.	443.	1.545	.991	

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 36

	240.			.032	.045
	282.			.036	.090
	339.			.113	.554
19.	40.	2.842	1.324		
43.	54.	1.149	0.000		
55.	80.	1.757	0.000		
81.	112.	1.495	1.514		
111.	154.	.878	0.000		
183.	195.	3.090	0.000		
197.	215.	2.667	0.000		
218.	236.	.203	3.315		
246.	278.	1.320	3.401		
281.	306.	1.802	0.000		
309.	334.	2.140	1.338		
337.	362.	1.545	3.536		
365.	390.	.604	2.653		
393.	418.	.599	2.694		
420.	446.	.842	.721		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 37

5.	33.	1.194	0.000
40.	54.	1.712	0.000
54.	82.	2.090	0.000
89.	110.	1.387	0.000
117.	128.	1.347	0.000
138.	152.	2.018	0.000
180.	194.	1.486	0.000
196.	210.	2.077	3.437
215.	236.	1.050	5.982
243.	278.	1.432	1.689
278.	313.	1.815	.721
313.	320.	1.964	3.351

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 38

	284.			.054	.005
	368.			.104	.036
5.	33.	.766	0.000		
40.	54.	2.527	2.284		
54.	80.	1.514	0.000		
81.	110.	1.054	0.000		
123.	130.	1.054	0.000		
180.	194.	2.820	1.027		
194.	210.	2.257	2.266		
208.	215.	3.622	1.302		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 39

	234.			.077	0.000
	269.			.041	.176
	298.			.036	.014
3.	33.	4.261	21.212		
40.	54.	1.212	17.883		
54.	68.	3.221	11.081		
89.	110.	1.212	8.369		
124.	152.	1.446	4.446		
180.	194.	5.563	1.590		
197.	215.	2.878	15.824		
215.	236.	2.964	1.914		
236.	278.	1.104	4.284		
278.	309.	15.207	0.000		
309.	334.	5.342	6.365		
343.	355.	15.387	12.243		
362.	379.	0.000	5.086		
398.	435.	0.000	4.500		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 40

3.	26.	2.572	0.000
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RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

MINER'S NUMBER = 41

	235.			.018	.730
	278.			.045	.050
	341.			.041	1.541
	374.			.072	.063
8.	32.	.595	0.000		
40.	53.	1.450	2.284		
54.	81.	1.532	.941		
82.	112.	.297	1.050		
117.	130.	2.730	0.000		
159.	179.	.946	.505		
180.	193.	.991	4.946		
194.	207.	4.437	2.203		
208.	235.	2.986	7.788		
243.	277.	.108	72.626		
278.	305.	3.941	7.356		
306.	334.	1.477	2.338		
341.	361.	2.054	2.126		
362.	389.	.626	1.455		
390.	417.	1.027	.725		
418.	438.	.734	1.820		

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 1

16.	35.	1.221	0.000
64.	91.	4.212	3.252
449.	466.	1.027	1.054

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
 SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 2

118.	146.	1.698	0.000
118.	510.	.586	2.892
161.	174.	.360	5.486
175.	188.	.185	0.000
205.	231.	.586	.946
223.	237.	0.000	1.117
238.	265.	0.000	1.018
266.	293.	.311	0.000
294.	328.	0.000	.887
329.	356.	0.000	.473
364.	391.	0.000	.473
392.	419.	0.000	1.167
420.	447.	0.000	1.072
448.	482.	0.000	.315

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 3

117.	145.	.176	.162
146.	175.	.095	.707
175.	190.	.257	.297
203.	234.	.135	0.000
235.	266.	.135	0.000
296.	310.	.135	0.000
326.	357.	.158	.041
365.	387.	0.000	.153
389.	418.	0.000	6.401
449.	494.	.104	1.563

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 4

122.	149.	.459	.527
180.	219.	.135	.793
210.	224.	1.365	0.000
225.	242.	0.000	1.878
271.	285.	0.000	.550
300.	315.	.514	0.000
348.	387.	.514	0.000

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 5

7.	34.	.171	.234
64.	91.	.369	.207
91.	118.	.167	.194
119.	132.	.225	.455
140.	174.	.162	.203
175.	202.	.878	0.000
245.	265.	0.000	.356
266.	293.	.077	0.000
294.	328.	.234	0.000
329.	356.	0.000	.293
357.	384.	.468	0.000
399.	419.	.149	1.396
448.	482.	0.000	.158

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 6

20.	27.	.189	.180
37.	63.	0.000	.122
64.	91.	.068	.023
64.	91.	.541	0.000
118.	141.	.288	0.000
142.	176.	.495	.018
170.	198.	.261	.739
228.	259.	0.000	.315

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL 'S NUMBER = 7

22.	28.	.221	.599
116.	116.	0.000	.009

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY		PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START	STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL 'S NUMBER = 8

29.	38.	.333	.018
38.	63.	.622	.018
134.	144.	.036	.486

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 9

8.	37.	.117	.477
37.	63.	3.342	0.000
86.	116.	.572	.005
116.	143.	.572	.005
174.	205.	.117	.514
205.	232.	.338	.090
228.	236.	0.000	2.054
237.	267.	0.000	.577
267.	296.	0.000	1.054
296.	327.	0.000	.275
327.	361.	.077	0.000
327.	419.	.077	0.000
420.	449.	0.000	.333

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 10

118.	147.	.464	.333
148.	175.	0.000	.455
175.	204.	.410	1.631
239.	266.	.059	2.414
267.	294.	.158	.667
295.	326.	0.000	1.023
336.	355.	0.000	.883
358.	385.	0.000	.662
386.	420.	0.000	.423
421.	448.	.437	0.000
449.	477.	0.000	.288

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD.
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 11

358.	391.	.955	0.000
392.	419.	0.000	.131
421.	446.	.640	0.000

RA-D AND RA-F SPECIFIC ACTIVITY FOR WHISKER AND BLOOD
SAMPLES IN PICOCURIES PER GRAM OF SAMPLE

DAY OF STUDY	PCI RA-D/G	PCI RA-F/G	PCI RA-D/G	PCI RA-F/G
START STOP	WHISKERS	WHISKERS	BLOOD	BLOOD

CONTROL'S NUMBER = 12

20.	34.	.189	.203
64.	84.	.234	.297
90.	118.	.230	.225
118.	139.	0.000	.122
139.	173.	.234	.167
173.	202.	.009	.090
203.	223.	0.000	.167
223.	237.	0.000	3.608
237.	265.	0.000	.378
272.	300.	0.000	.036
300.	328.	0.000	.072
329.	356.	0.000	.374
357.	391.	.257	0.000
392.	419.	.041	.122
419.	447.	.140	.113