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RU

PROGRESS REPORT 2

An Investigation of Radon-222 Emissions From Underground Uranium Mines

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February 1980

Prepared for the
U.S. Nuclear Regulatory Commission

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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Pacific Northwest Laboratory
Richland, Washington 99352

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ABSTRACT

A reliable estimate of radon emissions to the environment from underground uranium mines was obtained through measurements of radon in ventilation exhaust air at 24 uranium mines and estimates of radon release from ore piles and waste piles at mines and in water pumped from mines. Three additional mines sampled in 1978 but not in 1979 were included in the overall results. Total production of U_3O_8 from the mines thus far sampled represent about 63% of total 1978 U.S. production from underground mines.

Mine characteristics and production data were obtained from interviews with owners of mines representing more than half of 1978 production from underground uranium mines. Ore production and average grade as a composite of 27 mines in the study were furnished by the Grand Junction Office of the Department of Energy.

Wide variation in radon emission per unit of production was shown from mine to mine; hence, it became necessary to sum all radon from all mines measured and divide by the sum of all U_3O_8 production in 1978 from these mines to arrive at a valid estimate of Ci per ton of U_3O_8. This value was found to be 26.7 Ci per ton or 5400 Ci/RRY (182 metric tons). The radon emitted in mine ventilation air was by far the dominant source, with other than ventilation exhaust sources accounting for less than three percent of radon in ventilation exhaust.

Other observations of interest in this study were the diurnal fluctuations of radon with barometric pressure and the statistically significant relationship between radon released per year from a mine and the cumulative ore production at the time of radon measurement. The linear relationship between Ci/yr of radon and cumulative ore accounted for about half the variability.

Several sources of random errors and possible biases were evaluated using some simple descriptive statistics insofar as the current data permitted. Errors in air flow rate in the vents sampled, fluctuations in radon emission with time of day, counting instrument calibration and production rate were estimated and combined to give an uncertainty of about $\pm$ 24 percent at the 95 percent confidence level.

AN INVESTIGATION OF RADON EMISSIONS FROM UNDERGROUND URANIUM MINES

INTRODUCTION

Uranium mining is the first stage of the uranium fuel cycle and has received considerable attention because of concerns for miner health, which stem primarily from the presence of radon daughter products in the mine atmosphere. High ventilation rates for mine air have been the most effective means for reducing concentrations of radon and daughter products to acceptable levels in work areas; however, this ventilation control of mine atmospheres has resulted in the transfer of radon, its daughter products, and other gases and particles to the atmosphere.

In 1974 the U.S. Atomic Energy Commission (AEC) issued a report which addressed the environmental impacts of the uranium fuel cycle (USAEC 1974). Using the best available information, this AEC report evaluated the mining of uranium ore with respect to gaseous emissions and aqueous effluents to the environment and estimated the radiological significance of these waste products. The environmental release data were normalized to a reference reactor year (RRY, the annual U_3O_8 fuel requirement for a model 1,000-MWe light water reactor) and reported in Table S-3 of the referenced document. The estimated radon release of 75 Ci per RRY was soon challenged in reactor licensing, primarily because the value was derived from a rather insufficient data base and covered only radon releases from the milling of uranium ore.

The U.S. Nuclear Regulatory Commission (NRC), as part of its reactor licensing responsibility, subsequently sponsored research to determine radon and other emissions from mining operations as a function of ore and uranium production. Pacific Northwest Laboratory entered into a research contract with NRC, Office of Nuclear Regulatory Research in late 1977. During the initial months, emission sampling equipment and other apparatus were acquired and calibrated.

Several ventilation exhausts from uranium mines in the Grants Mineral Belt of New Mexico were sampled and radon measurements made in 1978. The results of these measurements were reported in an interim report issued in April 1979 (Jackson 1979). This report was revised and reissued in September 1979 to provide consistency with a report addressing radon release from open pit mining (Nielson 1979).

We have made many additional radon release measurements not discussed in the interim report. It is the purpose of this document to present results of the study that were reported but not interpreted in the first report and to present the results of new measurements of radon in uranium mine exhausts. Although the results reported here add significantly to the data base on radon release, this report is not a final report. Work still anticipated includes additional mine sampling.

Following a discussion of study objectives and structure, this report describes a) data base development designed to document mine information relevant to radon emissions, and b) an experimental program to measure radon emissions and disclose possible relationships between mine parameters and emissions.

OBJECTIVES AND STRUCTURE OF THE STUDY

The main objectives of the research are to characterize particles and gases released in uranium mine ventilation air and to determine the quantities released from the total mine operation per unit production of U_3O_8. Other objectives are to determine important independent variables with which the radon release can be correlated and to test these correlations to determine their statistical significance. Thus far the study has emphasized the emission of radon; however, the scope of the work included sampling and measurement of 1) radon daughter products, 2) other particulate materials, including water droplets, and 3) the more conventional chemical pollutants from mine activities such as blasting, diesel engine operation, etc. Estimates were also made for radon release from waste and ore stored at the mine. Pumped mine water was also considered.

The research plan for this work embraces four tasks, described briefly as follows.

TASK A: DATA BASE DEVELOPMENT

The objective of this task is to seek out and document information on underground uranium mines which would be relevant in some way to radon and other emissions from mines. Data believed to be important were production rate, age of mine, grade and mineralogy of the ore, water production in the mine, mine volume, ventilation practices, blasting, and ore removal cycles. Results of mine surveys and how the surveys were carried out are covered in this report.

TASK B: PARTICLE AND GAS EMISSIONS, CHARACTERIZATION AND EMISSION MODEL DEVELOPMENT

The objective of this task is to determine from many field measurements the nature and quantity of radioactive and nonradioactive particles and gases emitted from operating mine vents and from wastes and ore stored at the mine. Development of equipment and methods for this study was a necessary initial part of the task. Mine owners were contacted and permission obtained for the measurement phase of the study and information was obtained from them about the mine sampled and its operation during the sampling period. Sampling and measurements at the first mines were initially intensive as reported by Jackson et al. (1979). As radon release data were accumulated, relationships between release and independent variables were sought. In the first report (Jackson et al. 1979) we observed a relationship between life-time ore production (or ore volume) and radon release. We have been made acutely aware of the large variation in physical and operational variables, yet we have also become aware that some variables which were initially anticipated to significantly affect annual release of radon have only minor influence, such as blasting and normal changes in barometric pressure. Further findings in this respect are to be presented in this progress report.

Mines representing a large fraction of the U.S. uranium mining industry were sampled, so that if good correlations were not found between radon release and mine parameters, we would nevertheless be able to cite a general radon release term for the whole present mining industry and relate it to total production or RRY's from all underground uranium mines.

TASK C: ATMOSPHERIC DISPERSION, DEPOSITION, AND TRANSPORT

This task will address the fate in the environment of emissions from underground mines. Once the nature of emissions from the mine are characterized, concentrations downwind will be estimated using models and meteorological conditions. Account will be taken of dry and wet deposition processes for depositing solid and gaseous wastes on the land surface. Task C has not been undertaken, pending completion of the measurements in Task B.

TASK D: ENVIRONMENTAL ASSESSMENT

The objective of this task is to evaluate the potential impact of airborne emissions on human health. This task is also deferred until source terms for the mine are better defined.

TASK A - DATA BASE DEVELOPMENT

Principal Investigators: W. I. Enderlin, J. A. Glissmeyer

PURPOSE AND SCOPE

The purpose of Task A is to develop a data base that is relevant to the emission of radon from U.S. underground uranium mines and to characterize the mining operation with respect to the data obtained. The main objectives of this task are:

- Identify the parameters most likely to affect radon emission to the atmosphere.
- Survey with respect to the parameters to be considered a group of mines which is representative of U.S. underground uranium production.
- Characterize the mining operation with respect to the data obtained and identify additional data that should be obtained by other means.

The following methodology was used in performing this task. Thirty of the largest underground uranium mines in the U.S. were selected to be surveyed and ranked according to their 1978 annual production (Engineering and Mining Journal 1979). The basic underground mining operation (modified room and pillar), which is common to all of the mines selected, was reviewed to determine which variables would most likely affect radon emission via the mine ventilation system. Twenty-six of the selected mines were surveyed with respect to these variables by conducting field interviews with local mine management. The data that were common to all of the mines and the desired data unobtainable through mine interviews were identified.

The pertinent variables identified are tabulated in this report. The data analysis included calculating the distribution, average, and range for each of these variables. Finally, the mining operation was characterized in terms of the data obtained, and the uncertainties and need for additional data are discussed.

VARIABLES GOVERNING RADON EMISSION

The primary function of the mine ventilation system in a U.S. underground uranium mine is to maintain the concentration of radon daughter products and silica below current standards in all active working areas of the mine to protect the health of personnel. It is the radon daughters, RaA and RaC', that constitute the important health hazard to miners and not radon gas (^{222}Rn), which, although an alpha particle emitter, is retained in the lungs to a much lesser degree than the daughter products.

In the past there has been little concern over the concentration of radon or radon daughters in the ventilation exhaust plume at the surface. Consequently, very little information on this topic is available in the open literature.

Sufficient data are currently unavailable to correlate mine production rate with the concentration of radon daughters in the ventilation exhaust plume, and considerably more investigation is necessary before such a correlation can be attempted.

The following information provides a basis for further study.

Prior investigations have shown that the following are the primary sources of radon daughter contamination in mine ventilation systems:

- radon emanation from wall rock
- radon released from ground water
- radon released from broken ore
- suspended mineral dust
- radon released at the instant of blasting
- leakage from abandoned workings.

It is an accepted belief throughout the industry that the following factors have a significant influence on the influx of radon and on the rate of growth of radon daughters in the mine atmosphere:

- Grade of ore - There is no established direct relationship between ore grade and the amount of radon retained in the ore; however, the rate of radon emanation tends to increase with grade up to at least 0.55 grade (10 lb U_3O_8/ton) (Bossard et al. 1974).

- Fluctuations in atmospheric pressure - A 1.5% increase in atmospheric pressure (1 cm Hg) can result in a 5- to 20-fold decrease in radon emanation from wall rock (Rock and Walker 1970).

- Rate of advance and size of broken ore - About 5% of the available radon in the rock is released at the instant of blasting (Thompkins 1974). Radon emanation from broken ore increases with greater fragmentation of the ore. Overblasting that opens cracks extending into the ore zone further increases radon emanation from the wall rock.

- Quantity of ground water contact with the mine ventilation air stream - Most of the radon entrained in ground water is liberated to the mine atmosphere as soon as the water leaves the rock. Concentrations of radon in ground water entering uranium mines have been reported to range from 5.17×10^2 pCi/ℓ to 8.12×10^4 pCi/ℓ (Bossard et al. 1974).

- Quantity of exposed rock surface - The amount of exposed rock surface in the mine is a function of the type of mining method used and the age of the mine. The average known radon emanation rate for New Mexico sandstones in place is 5×10^{-14} Ci/(cm^2·s); whereas it is 5×10^{-15} Ci/(cm^2·s) for Utah shales (Thompkins 1974). However, the emanation rate will often vary by factors of 100 or more between districts and between areas within a mine.

- The resident time of the ventilation air - The longer the air residence time the higher the degree of equilibrium between radon and its daughter products. A low degree of equilibrium together with high radon daughter concentration in the exhaust air stream suggests a high radon emanation rate in the mine. Equilibrium is reached in about 3 hours when the concentration of the respective decay-series members remains constant.

- The amount of ore handling underground - A sudden liberation of radon occurs each time broken ore is disturbed. Radon emanating from ore samples ranges from 7 to 57% (Bossard et al. 1974). One cubic yard (2 to 2-1/2 tons) of ore in place with 20% porosity contains about 150×10^6 pCi of interstitial radon (Bossard et al. 1974).

- The type of mine ventilation system - Parallel ventilation systems are preferred to series systems because air residence time and mine resistance to air flow is less. The mine may also use a blowing system, an exhausting system, or a combination of blowing and exhausting (push-pull) systems. Each type of system affects the radon emanation rate in a different way. Mine operators endeavor to keep fresh inlet airways in barren rock and exhaust airways in ore.
- Porosity and permeability of the rock - Radon emanation rates are greater with higher rock porosity and permeability.

Based on the foregoing, it is obvious that not all factors that may influence the concentration levels of radon decay products in the ventilation air circuit are related to the rate of ore production.

Furthermore, the primary sources of radon have not been well quantified. Even so, it is believed that most of the radon entering the ventilation system emanates from the exposed wall rock. This conclusion was supported in the first report in this study, which showed a significant correlation to exist between mine surface area and radon emissions (Jackson, et al. 1979). Moreover, the sensitivity of each of the factors believed to influence radon influx to variations in the mining operation is also not well understood.

SCOPE OF SURVEY

All of the factors identified as having a significant influence on radon influx into the ventilation air circuit were incorporated into the design of the data sheet (Figure 1) used in the mine survey with the exception of the quantity of exposed rock surface, ventilation air residence time, and rock porosity and permeability. Mine operators do not normally have data pertaining to these parameters.

Of the thirty mines selected for survey, operators of twenty-six agreed to participate in the survey with the understanding that the data obtained would not be identified in the open literature with a particular mining operation. We estimate that the total 1978 ore production for the surveyed mines represents about 64% of the total U.S. underground uranium ore production for 1978 and about 27% of the total U.S. uranium ore production for that year. The rationale for this estimation is discussed in Appendix A.

UNDERGROUND MINE SURVEY DATE__________

Mining Company______________________________

Name of Mine ______________________________

Mine Location ______________________________

Principal Contact ______________________________

Telephone ______________________________

Production

Description of Mining Method:

Daily Ore Production Rate ______________________Ton/day

Total Mine Production to Date

Ore__________Ton

U_3O_8__________lb

Ore Grade (% U_3O_8)

Average Grade __________

Cutoff Grade __________

High Grade __________

Mine Grade __________

Production Shifts ______________________Shift/Day

Active Mining Areas ______________________Areas/Shift

Blasting Frequency ______________________Blast/Area/Shift

Size of Mine Run Rock (Ore) ______________________in.

Description of Ore Handling Sequence in Mine:

FIGURE 1. Sample Data Sheet

Ore Resident Time in Mine ____________________________ Shifts.

Production Start Date ________________________________

Expected Mine Life ________________________________ yrs.

Mine Water Discharge Rate ____________________________ gpm

Is Mine Water Used in the Mine? ______ yes, __________ no

If yes, How? ______________________________________

Are Mill Tailings Used for Backfill? ________yes, _____ no

VENTILATION

Total Mine Air Balance _______________________________ cfm

Type of System: Blow _____, Exhaust ________, Push/Pull ______________.

Number of Air Intakes: Shaft __________, Adit ________, Bore Hole _____.

Number of Air Exhausts: Shaft __________, Adit ________, Bore Hole_____.

Furnish a List of Air Exhausts Giving Type, Size, and Flow Rate (cfm).

Air Exhaust Outlets Are ______Vertical _________, Horizontal ___________.

Air Exhaust Outlets Are ______ft. Above Grade.

Service Power (110 V) Available at Exhaust? ________ yes, ___________ no.

FIGURE 1. Sample Data Sheet (contd)

The mines surveyed were located in the major uranium mining districts of New Mexico, Wyoming, Colorado, and Utah, as shown in Figure 2.

Of the mines surveyed, 63% were located in New Mexico and represent 74% of the total production of the sample; 25% were located in Wyoming, accounting for 14% of the production; 12% were located in the Colorado/Utah district, representing 12% of the production.

SURVEY RESULTS

Data were obtained for the following mine parameters, which were determined to be of primary concern:

- daily ore production
- average ore grade
- cumulative ore production
- total mine air balance
- years in production
- mine water discharge rate.

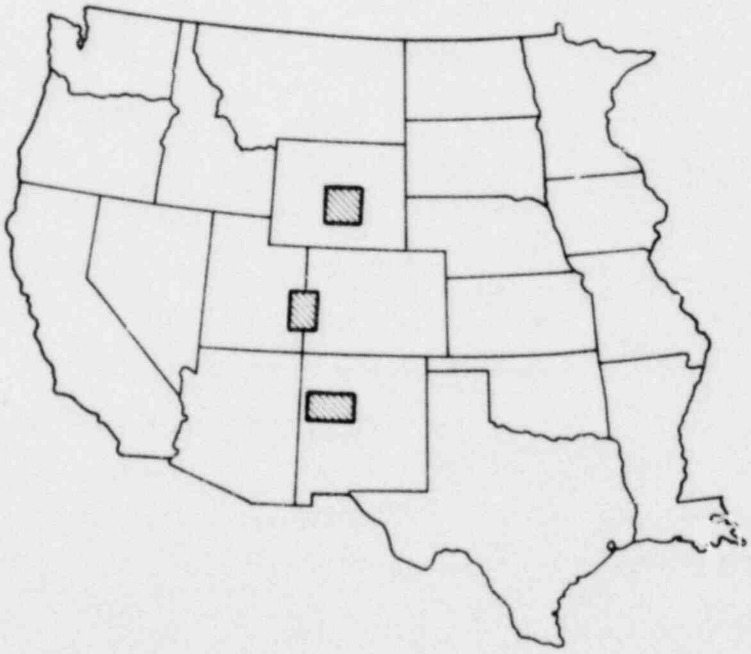

FIGURE 2. Geographical Location of Major Uranium Mining Districts

All other parameters of interest were found to be common to all of the mines surveyed. The data pertaining to these variables appear in Table 1 and the statistical summary of the data appear in Table 2.

Daily ore production was reported by 24 of the mines surveyed, yielding a total of 15,600 tons for the sample for an average production of 650 tons per working day. Production rate for the sample ranged from 114 tons/day to 2630 tons/day. The distribution of the daily production rate ranges for the sample is shown in Figure 3. It can be seen from Figure 3 that of the 24 mines reporting daily ore production, 58% fall between 200 tons/day and 600 tons/day.

Average ore grade was reported by 24 mines, yielding an average grade for the sample of 0.167% U_3O_8. The grade for the sample ranged from 0.055% to 0.472%. The distribution of the average ore grade ranges for the sample is shown in Figure 4. It can be seen from Figure 4 that of the 24 mines reporting average ore grade, 75% have an average grade between 0.10 and 0.19.

Cumulative ore production was reported by 17 mines and ranged from 0.15×10^6 tons to 4.7×10^6 tons with a sample average of 1.77×10^6 tons. The cumulative ore production values reported in Figure 5 tend to be grouped into three distinct categories: less than 1×10^6 tons, 1×10^6 tons to 1.9×10^6 tons, and greater than 1.9×10^6 tons, with about 1/3 of the mines in each category.

Total mine air balance was reported by 24 mines, yielding an average for the sample of 274×10^3 cfm. The values ranged from 40×10^3 cfm to 850×10^3 cfm. The distribution of air flow ranges for the sample are shown in Figure 6. It can be seen from Figure 6 that there is a wide distribution of values. About 13% of the mines had total air volumes of less than 100×10^3 cfm; whereas 62% had total air volumes between 100×10^3 cfm and 399×10^3 cfm and 25% were in excess of 399×10^3 cfm.

TABLE 1. Mine Survey Data

Mine	Daily Ore Production (ton)	Total Avg. Ore Grade (%)	Mine Air Balance (Mcfm)	Mine Air Pressure (N/P)	Years in Production (yr)	Total Ore Production (MM ton)	Mine Water Discharge (gpm)
A	2190	0.19	420	N	3		3800
B	712	0.239	433	N	9	1.2	1630
C	946	0.213	376	N	9	1.8	305
D	1070	0.2	275	N	7	1.5	800
E	1000	0.161	575	N	21	3.9	360
F	715	0.190	371	N	20	4.7	345
G	794	0.177	218	N	4	0.45	220
H	480	0.101	500	N	21	2.6	200
I	300	0.12	628	P		1.8	25
J	368	0.190	181	N	20	2.4	920
K	352	0.472	240	N	19	1.4	1605
L	250	0.055	56	N	29		-0-
M	350	0.115	280	N	22		80
N	350	0.115	120	N	22		80
O	200	0.115	100	N	22		80
P	200	0.115	90	N	22		80
Q	-0-	-0-	-0-				
R	114	0.179	130	N	20	3.0	530
S	80	0.14	?	N	3	0.63	2
T	420	0.20	405	N			-0-
U	500	0.15	345	N	4	0.37	-0-
V	550	0.11	170	N	2	0.15	-0-
W	-0-	-0-	40	N	22		
X	550	0.18	358	P	4	0.21	275
Y	2630	0.153	850	N	6	2.4	1200
Z	500	0.136	136	N	17	1.6	250

M = 1000 N = negative P = positive

Note: For some mines the owners reported their daily mine production based on a 365- or 350-day per year operation. The production rate has in all cases been normalized to a 250-day working year so that all entries are on the same basis and the annual production can thus be obtained by summing the table entries and multiplying by 250.

TABLE 2. Statistical Summary

	Daily Ore Production (ton)	Avg. Ore Grade (%)	Total Mine Air Balance (Mcfm)	Years in Production	Total Ore Production (MM ton)	Mine Water Discharge (gpm)
ΣX_i	15,600	4.014	6575	328	30.11	12,787
N	24	24	24	23	17	24
$\overline{X}$	650	0.167	274	14.26	1.77	533
r	114-2630	0.055-0.472	56-628	2-29	0.15-4.7	0-3800

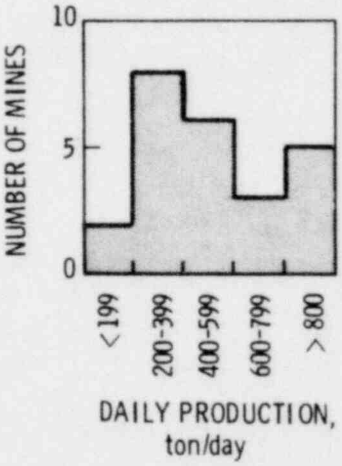

FIGURE 3. Daily Production Frequency

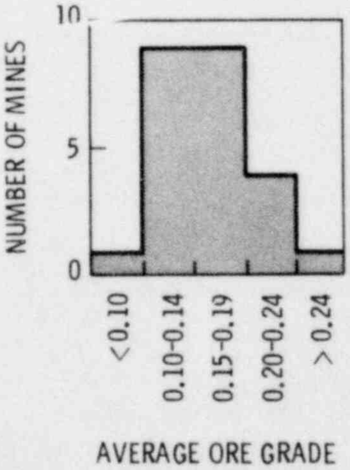

FIGURE 4. Ore Grade Frequency

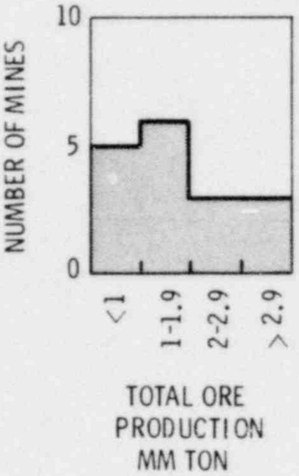

FIGURE 5. Cumulative Ore Production Frequency to Date

The total number of years in production was reported by 23 mines, yielding a sample average of 14 years. The values ranged from 2 years to 29 years. The mine age frequency distribution in Figure 7 shows that the mines sampled tend to be grouped in 3 distinct age categories, with 43% at less than 10 yr, 22% between 10 and 20 yr, and 35% greater than 20 yr.

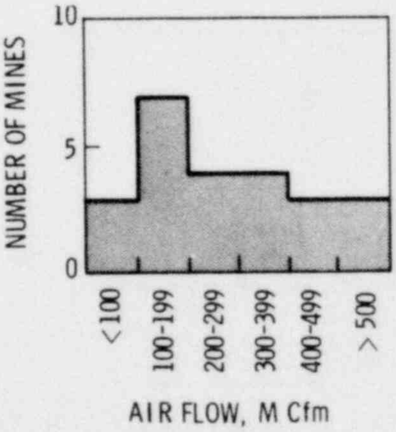

FIGURE 6. Ventilation Air Flow Frequency

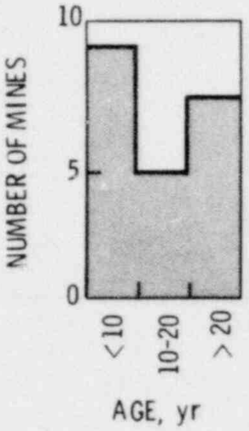

FIGURE 7. Mine Age Frequency

Mine water discharge rate was reported by 24 mines and ranged from 0 to 3800 gpm, with a sample average of 533 gpm. The water discharge rates reported in Figure 8 tend to be grouped into three distinct categories, with 42% being less than 200 gpm, 29% ranging from 200 to 400 gpm, and 29% being greater than 400 gpm. Four of the mines surveyed had abnormally high discharge rates, in excess of 1000 gpm.

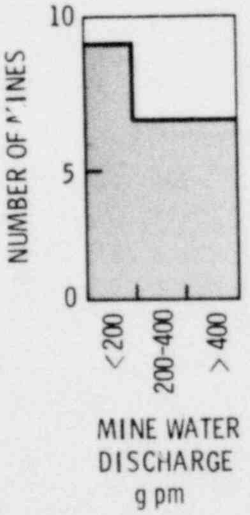

FIGURE 8. Mine Water Discharge Volume Frequency

CHARACTERISTIC MINE

A characteristic mine based on this survey could be described according to mining method, ore production, water discharge, and ventilation.

Mining Method

All the surveyed mines were modified room-and-pillar mines with stopes in ore and in most cases haulage in barren ground. In most cases, the ground is allowed to cave in the mined-out areas, resulting in increased liberation of radon from the rock adjacent to the ore zone.

Production

Ore is normally blasted in each active heading at midshift and at shift change, advancing about 6 ft per blast. Production is on 2 shifts per day, 5 days per week with a daily output of 500^{+500}_{-300} tons/day of $0.17^{+0.02}_{-0.07}$ grade ore. Production is in dry to moderately wet, loosely consolidated sandstone, which is indicative of relatively high porosity and permeability, and hence high radon emanation. The average mine has been in production 14^{+11}_{-9} years and has a cumulative ore production of $1.77 \times 10^6 \, {}^{+1.27 \times 10^6}_{-1.27 \times 10^6}$ tons.

Mine Water Discharge

The mine is dry to moderately wet, with a water discharge rate of less than 400 gpm. The water may or may not enter the mine via the ore zone and hence may or may not contribute to the influx of radon.

Ventilation

An exhaust ventilation system with a parallel underground network is employed. The entire mine, including inactive areas, is maintained at a negative pressure, hence inducing radon influx. The total air flow rate through the mine is probably between 100×10^3 cfm and 400×10^3 cfm. Total air transit time is anticipated to range from 20 min to 50 min.

TASK B. RADON MEASUREMENT PROGRAM

Principal Investigator: P.O. Jackson

OVERVIEW - GENERAL APPROACH

The primary purpose of this task is to determine through measurements and other observations the curies of radon entering the environment from the U.S. production of uranium from underground mines. Four sources of radon release to the atmosphere are: mine ventilation air, waste from the mine deposited near the mine, temporarily stored ore at the mine, and radon released from water pumped from the mine. Of these, radon exhausted in ventilation air is by far the most important, but each will be addressed in this section.

Radon in mine exhaust was to be measured at mines whose total production represents a large fraction of the U.S. current production of uranium. Eventually, with enough mine data and radon measurements, it might prove feasible to determine relationships between mine variables and radon release, but the emphasis on the work to be reported is the experimental measurement of radon released from a large segment of the uranium underground mining industry. Initial observations will be made of apparent relationships, or lack of correlation.

Based on studies of the variability of radon concentrations made in 1978 (Jackson et al. 1979), we concluded that a grab sampling program was feasible and acceptably adequate since the relative standard deviations of sequential concentration measurements at mine vents ranged from only 9% to 30% over about a month interval. We have continued and expanded the grab sampling program initiated in 1978. In addition, we have attempted to define the accuracy of the grab sampling approach by studying long-term and short-term variations in radon output from mine vents. We have also attempted to evaluate the accuracy of each variable used in the expression defining the overall average output of radon. These detailed studies are not completed at present, but sufficient data have been gathered to permit a reasonable evaluation.

Briefly, our grab sampling program consists of filling a duplicate set of evacuated scintillation flasks with air from each mine vent. The sampling is repeated on another day. Most of the locations sampled in the fall of 1978 were resampled in the spring of 1979 to examine longer-term variations. Flow rate measurements are then used to determine the radon output per unit of time.

Radon output from other than ventilation air sources was determined from the approximate dimensions of aboveground ore and mine waste storage areas, from the U_3O_8 content, and from estimates of radon exhalation per unit content of U_3O_8. An estimate was also made for radon from pumped water.

Production of U_3O_8 for 1978 for the total of the mines sampled was obtained from the Grand Junction, Colorado Office of the Department of Energy. Production of individual mines was obtained from mine operators, but could not be obtained for all mines sampled. Individual mine production is needed to investigate radon release as a function of mine parameters. We have assigned alphabetical descriptors to each mine rather than using company names. English and metric units have been used in the report according to practice in the mining industry.

EXPERIMENTAL: FIELD RADON SAMPLING AND MEASUREMENT

Extent of Mine Sampling

During the interval from September 1978 through September 1979, we collected ventilation air samples from twenty-seven underground uranium mines. These mines represented a total production of 3,600,000 tons of ore in calendar year 1978 with an average grade of 0.16% U_3O_8 or 5230 metric tons (tonnes) of U_3O_8. This quantity compares with 6,105,000 tons of ore containing 8350 metric tons of U_3O_8 for all U.S. underground uranium mines (U.S.DOE 1979). The mines investigated thus represent about 63% of the total. The sampling program included some small mines not included in the survey conducted in Task A. Mines in Wyoming were not sampled. The number of mines, vents, and measurements made in 1978 and 1979 are shown in Table 3.

In addition to the vent air sampling program, we investigated the physical characteristics of aboveground waste and ore storage piles for seven of the mines.

Production from the mines sampled varied from virtually zero to nearly 700 metric tons of U_3O_8 per year. Some mines with no or very little production are ventilated to prevent radon-contaminated air from flowing into interconnected active mines, or in some cases the zero-production mine may be used as a haulage way.

TABLE 3. Summary of Vent Air Sampling Programs

	1978	1979
Number of Mines* Sampled	14	26
Number of Vents Sampled	71	139
Number of Measurements	247	369

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* U_3O_8 production from these mines represents 63% of total U.S. production from underground uranium mines.

Mine Vent Sampling for Radon

Grab Sampling

Duplicate samples were collected from each vent by drawing vent exhaust air into an evacuated 6-in diameter acrylic cylindrical vessel of 1136 cm^3 volume. The internal surfaces were prepared by spray-coating with a mixture of flourescent zinc sulfide contained in clear coil dope and the outside surfaces were sealed with white enamel. Exhaust air from the vent was passed by impact pressure through a sampling tube consisting of a small funnel connected to a 6 ft length of copper tube. The funnel-support end of the copper tube was formed into a bend, permitting the funnel to be held with the flared end facing into the exhaust flow. The lower end of the copper tube was connected to the evacuated scintillation flask through a high-efficiency filter and a flexible connector. The filter removed water droplets and particles containing radon daughter products. The section of tubing and funnel were flushed for a period of time and left filled with vent air before connecting the line to the scintillator flask. The stopcock on the flask was then opened until atmospheric pressure was reached, taking about 20 sec, then closed. After the scintillation vessel was removed, the stopcock was again momentarily opened to insure pressure equalization with the atmosphere. Samples were returned to a mobile laboratory and held for intervals from five hours to overnight to permit equilibration. The alpha particle emissions were determined using scintillation counters described in an earlier report (Jackson et al. 1979).

Continuous Radon Monitoring

In 1978 we collected and measured sequential samples from two mines integrated over four-hour sampling periods, thus yielding six samples in 24 hours. Samples were collected in this mode over a one-month period. Short term fluctuations in radon emission relative to the sampling period might not have been detected in this sequential sampling system.

A commercial continuous radon monitor was used at the end of the 1978 field program and again in 1979.[1] The purpose of this instrument was to record more rapidly changing radon concentrations. With this system the concentration of radon is measured while the air flows through a scintillation chamber. The output of the scintillator is integrated on a scaler for fixed intervals, a permanent record is printed at the end of each interval, and the scaler resets to zero to permit another count. This system was used with 20-minute integration intervals.

Since the radon daughters born in the scintillation chambers tend to plate out on the active scintillation surfaces, these units have a delayed response to rapid changes of radon concentration. We have used a decay correction calibrating procedure developed by Thomas (Thomas, June 1979) to improve the response characteristics of the unit. In this method the current count is corrected for the daughters deposited during the preceding six to eight counts. The corrected concentrations have been stored in computer arrays. Maximum and minimum values as well as averages and standard deviations for each collection period have been determined. These data were taken to estimate possible biases in our estimates of integrated radon release from grab sampling.

Ventilation Exhaust Flow Measurements

Exhaust flow measurements posed special problems due to the non-ideal configuration of the fan and exhaust discharge duct. In some cases a vortex

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[1] Model RGM-1, Eberline Instrument Co., Santa Fe, New Mexico.

was created because of the nearness of the fan. Access holes in the vent wall for pitot tube measurement were infrequently available. Protective screens, and in a few cases, flared exhausts had to be dealt with. Vent air velocities were generally in the range of 1000 to 5000 fpm, permitting a standard measurement with a pitot tube of good accuracy when access holes upstream of the exhaust fan were provided. Totalizing vane anemometers were used in most cases.[1]

After measuring the vent diameter, we selected 10 or 20 traverse points which divided the cross section into five equal concentric areas using a standard method (Rock et al. 1971).

Initially, when the vent was traversed, the instrument was fixed at each position for thirty seconds. Later we attempted to compensate for circumferential flow discontinuities by slowly moving the anemometer back and forth in an arc of about sixty degrees at each traverse radius. At six mines we measured enough vents to verify the measurements of the mine operator, and used his reported flows on the remaining vents.

Factory calibrations in the range of 100 to 800 ft/min were rechecked in our laboratory prior to use. The anemometers had limited service life before bearing failure in our application. When a unit failed, several previous traverse points were remeasured using a different instrument.

A brief study was conducted of flow variations over a period of a few days at two mine vents. A vane anemometer[2] with a.c. electric analog output was positioned in the exhaust air stream. The output was registered on a strip chart recorder. Since the velocity exceeded the range of the anemometer, a mask with apertures was provided to reduce flow through the instrument. Velocity changes with time were recorded.

Non-Ventilation-Exhaust Sources of Radon

Rationale for Estimating Radon Release

Three sources of radon emission to the atmosphere other than from mine exhaust are:

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[1] Two were Davis high speed Units, Davis Instrument Mfg. Co. Inc, 513 East 36th Street, Baltimore, MD. Two others were Weathermeasure Model W 131. Weathermeasure Corporation, Box 41257, Sacramento, CA 95841.

[2] Weathermeasure, Model W 132, Direct Reading Air Meter. Weathermeasure Corporation, Box 41257, Sacramento, CA 95841.

- waste piles at the mine
- ore storage at the mine
- radon released from mine water discharged above ground

Each will be discussed in this section with a description of field measurements and the analytical approach used to arrive at the estimates of radon release.

Waste Piles at the Mine

A wide range of practices of discarding waste was observed in field surveys and also brought out in discussions with mine personnel. At some mines the waste was spread in a thin layer as shallow as one foot in depth; at other mines the waste was piled to a depth of over 20 ft. The choice of practice depends on the need for fill such as for road grading and also on the area available for the waste pile. Another more recent consideration is the favorable economics of recovering uranium from much lower grade ore. Waste piles more easily accessed for hauling to the mill would thus be expected. We observed the processing of waste in some cases. The wide variability in waste discard practices and cut-off grade thus make radon estimates from mine waste very imprecise. In principle, if we could determine the exposed surface area and the average uranium content, it would be possible to estimate exhalation rates through knowledge of radon release per unit area per unit concentration of uranium in soil.

We characterized the geometry of waste piles at two mines by measuring the length, width, and height. Five other mine waste piles were measured and described by mine personnel. Mine age, total production, and current production were also obtained for four mines.

The surface area of the waste pile was estimated with the assumption that the pile could be represented by the frustrum of a right pyramid whose base was the measured dimensions and whose height was the measured height of the pile. The sides made an internal angle of 60° with the base. Pile volume was also calculated. When the area of the base was known but not the dimensions, the base was assumed to be square. The diffusion-exhalation method of Nielson et al. (Nielson et al. 1979) was applied to estimate radon exhalation using the specific radon exhalation rate of 0.092 $\mathrm{Ci/(m^2 \cdot yr \cdot \%\ U_3O_8)}$.

An exception was made for calculating emissions from the waste pile which was only one foot thick. For this pile, we used the same method used for the ore.

A small correction as a credit was taken for reduced radon emission by covering the natural soil with the thicker waste piles. The radon release values are shown in the RESULTS AND DISCUSSION section.

Table 4 shows the dimensions and other statistics determined currently for the seven mine waste piles and for the same piles projected to the end of life of the mine (assumed to be 30 yr total life). The projection was based on the ratio of annual ore to waste production for the mine or an average ratio of 7.3 based on the composited tons of ore and waste for 1978 obtained from seven mines.

Three mine waste piles shown in Table 4B could not be extrapolated to their size at end of mine life because of insufficient data regarding current mine age or the current waste pile geometry. Sample calculations are shown in Appendix B.

Ore Storage at the Mine

Ore storage practices at the mine also differ widely from mine to mine. Generally, one week to one month's production is stored on the designated ore pad near the mine. The assumption for estimating radon release from this source is that all "available" radon is released as it is born following placement on the ore pile. Prior handling is assumed to have released the interstitial available radon. The radon "available" for release is taken to be 0.2 of the total and represents the fraction of radon present not trapped within the mineral crystal matrix. The assumption of total release of the available radon as it is born will lead to somewhat higher predicted releases than would actually occur from the diffusion process.

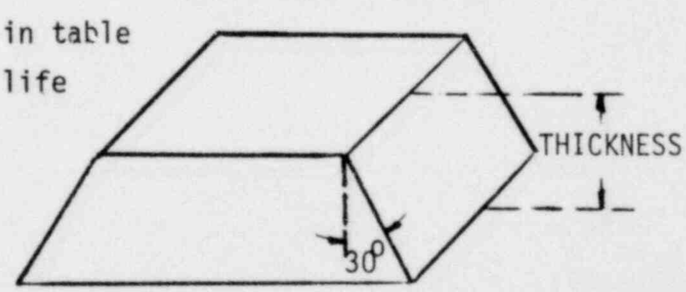
Ore storage statistics were obtained for five mines and are shown in Table 5.

Mine FF, although used for estimating radon release from waste piles, could not be used for estimating radon release from stored ore since there was neither production nor ore storage at the time of this writing.

TABLE 4. Statistics Used for Estimating Radon Emissions from Mine Waste Piles

Mine I.D.	Base (ft^2)	Thickness (ft)	Grade (% U_3O_8)	Total Weight (tons)	Specific Volume (ft^3/ton)	Surface Area (meters^2)
			A. At the Present			
V	89,000	15.3	0.031	60,000	21.4	9,200
GG	58,000	7.6	0.030	21,000	17.0	5,800
E	220,000	21.8	0.040	243,000	18.5	220,000
H	186,000	21.2	0.043	183,000	20.4	192,000
FF	65,000	6.8	0.033	25,000	17.3	6,400
G	770,000	4.0	0.025[1]	163,000[1]	18.9[2]	72,000
F	2,000,000	1.0	0.025[1]	106,000[1]	18.9[2]	188,000
			B. At End of Mine Life			
V	600,000	21.5	0.031		21.4	60,000
GG	(3)	--				
E	480,000	21.8	0.040		18.5	48,000
H	330,000	21.2	0.043		20.4	33,000
FF	(3)					
G	1,540,000	11.5	0.025[1]		18.9[2]	146,000
F	(3)		0.025[1]		18.9[2]	

WASTE PILE GEOMETRY:



(ASSUMED TO BE A FRUSTRUM OF A RECTANGULAR PYRAMID)

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1. Estimated
2. Average value of first five mines in table
3. Insufficient data to project mine life

TABLE 5. Statistics Used for Estimating Radon Releases from Ore Stored at the Mine

Mine I.D.	Age (yr)	Production (tons/day)	Grade (% U_3O_8)	Removal Frequency (per week)	Average Stored U_3O_8 (tons)
V	2	550	0.11	1.0	1.5
GG	--	150	0.16	0.231	2.6
E	21	1000	0.16	2.0	2.0
H	21	550	0.10	1.0	1.4
G	4	790	0.18	0.5	7.1
F	20	720	0.19	0.5	6.8

Radon release estimates from ore storage are presented and discussed in the RESULTS AND DISCUSSION section.

Radon Release From Mine Water Discharged At Surface

Release from water was identified as a source of radon entering ventilation air in Task A (See page 8). Residual radon remaining in water pumped from mines will constitute a release to the environment primarily through the air as radon escapes from the water in the turbulent mixing of discharge. The contribution from this source was estimated from the data base on water pumped from mines and observations of radon content of some mine waters.

Because of the relatively low solubility of radon in water, much of the dissolved radon will escape when stagnant water-air interfaces are created and particularly when turbulence occurs. Thin films of water on rock surfaces following seepage, cascading water, and flow in open mine ditches to sumps give ample opportunity for release of radon within the mine.

Radon concentration in mine water has been reported in several studies (Misage 1975; Bykovsky 1973; Schiager 1968) and many measurements have been made on radon in natural waters (Turner et al. 1961; Kobal et al. 1972; Stenstrand et al. 1979; Mastina et al. 1974). Concentrations up to about 1 μCi per liter were reported in some artesian well water and in water from bore holes

(Stenstrand et al. 1979). Radon concentrations in mine water fell rapidly with distance traveled in the mine and the sampled water in most cases was not collected at the surface discharge point.

In 1979 Pacific Northwest Laboratory measured radon in water being pumped from five mines (Jackson et al. 1980). Radon in excess of that in equilibrium with radium-226 present ranged from about 220 to 830 pCi/liter, and although relatively few mines were represented in this brief study, we have chosen to estimate radon release from these data. Radon concentration in a given mine water was used with the respective mine water flow rate to arrive at a radon emission rate for the five mines. A tacit assumption is made that this radon is immediately released from the water to the atmosphere. The resulting contribution to the atmosphere is presented in the RESULTS AND DISCUSSION section.

Jackson (Jackson et al. 1980) also measured the quantitiy of radium-226 in these mine water samples and in the associated solids in the water. The fraction of radium associated with solids was potentially altered by lowering the pH after sampling to prevent plate-out. This procedure makes questionable the fraction of the radium associated with the solids. We have not included as contributing to the source term radon releases from radium either dissolved in water or as solids.

RESULTS AND DISCUSSION

RADON EMISSION IN VENTILATION EXHAUST AIR

Grab Samples Taken at Mine Vents

The average radon emissions calculated from samples taken in 1978 and 1979 from underground mine vents are listed with the standard deviation in Table 6. When more than one vent at a single mine was sampled, the samples taken from each vent were averaged and the averages for the several vents were summed.

Results of mines sampled both in 1978 and 1979 are shown separately so that changes which occurred over the interval of about 6 months could be shown.

The total radon emission rate for all mines sampled was 150,000 ± 2000 Ci per yr. This error term represents the root mean square (rms) of the replication errors (standard deviation). A more detailed examination of these variations was made using an analysis of variance technique which separated measurement error between replicates from temporal variations. This approach yielded a series of estimates for these errors at each vent and mine. The combined standard deviation for the sum of all mines was 3000 Ci vs the 2000 Ci rms estimate. This error term is an index to reproducibility alone and does not reflect possible accuracy errors which will be discussed in a later section.

The average ratio of 1979 to 1978 results for those mines sampled in both years was 1.18 ± 0.05. Although there appears to be a significant increase from the mines sampled in 1979 compared with those sampled in 1978, analysis of other sources of variation indicates that the increase may not be significant.

The radon release rates shown for mines G and K are based on grab samples taken in 1979 and month-long sequential samples taken in 1978. Although grab samples were also taken in 1978 at these vents, they were taken during a time of heavy rain, suggesting a falling barometric pressure. We have chosen to use the sequentially-taken long-term samples as the more valid determination of radon release in 1978. In both cases, however, the 1979 grab samples agreed more nearly with the 1978 grab samples than they did with the 1978 sequential long-term sample. Had we chosen to use the grab samples for all comparisons, an overall 1979/1978 ratio of 1.13 would have resulted. (The sequential sample

TABLE 6. Summary of Radon Emissions from Underground Mine Vents

Mine	1979 Measurement Ci/yr	1978 Measurement Ci/yr	Overall Average Ci/yr	Ratio 1978-1979
A	7,400 ± 1100		7,400 ± 1100	
B	4,700 ± 60	4,300 ± 100	4,500 ± 300	1.09 ± 0.03
C	5,200 ± 200	3,900 ± 300	4,600 ± 800	1.33 ± 0.11
D	3,630 ± 120		3,630 ± 120	
E	29,800 ± 400		29,800 ± 400	
F	9,200 ± 270	9,500 ± 200	9,400 ± 200	0.97 ± 0.03
G	2,150 ± 50	1,460**	1,800 ± 400	1.47 ± 0.03
H	15,200 ± 300		15,200 ± 300	
I	1,690 ± 80		1,690 ± 80	
J	7,760 ± 190	8,100 ± 400	7,900 ± 200	0.96 ± 0.05
K	7,000 ± 190	5,870**	6,400 ± 700	1.19 ± 0.03
L	1,470 ± 40	1,320 ± 30	1,400 ± 90	1.11 ± 0.05
M-Q	Not Sampled			
R	15,000 ± 400	14,600	14,800 ± 300	1.03 ± 0.04
S	Not Sampled			
T	1,890 ± 120		1,890 ± 120	
U	890 ± 20		890 ± 20	
V	1,010 ± 60		1,010 ± 60	
W,X	Not Sampled			
Y	17,500 ± 400		17,500 ± 400	
Z		2,640 ± 70	2,640 ± 70	
AA	2,100**	1,490 ± 70	1,800 ± 400	1.41
BB	2,130 ± 80	1,840 ± 70	2,000 ± 200	1.16 ± 0.06
CC		2,120 ± 50	2,120 ± 50	
DD		960 ± 40	960 ± 40	
EE	6,500 ± 70		6,500 ± 70	
FF	2,510 ± 80		2,510 ± 80	
GG	190 ± 7	146 ± 3	170 ± 30	1.30 ± 0.05
HH	1,040 ± 60		1,040 ± 60	
II	470 ± 10		470 ± 10	
		SUM ALL MINES ± STD. DEV.	150,000 ± 2000 (± 3000)	1.18 ± 0.05 AVE.

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* Single sample

** Average of sequential sample data, 1978 results for G and K in 1978 were used along with grab samples for other mines and other mine data to determine the radon per RRY as reported in PNL 2888 Rev, NUREG/CR-0627.)

As developed in Appendix C we have shown that uncertainties arising from our grab sampling schedules would be of the order of ± 10%. The estimate is derived using monitored data from the two mine vents showing the widest variation of radon concentrations.

Errors in determining the radon release rates are discussed in Appendix C.

Continuous Radon Measurements

The continuous radon monitors were operated at four mine vents, the primary purpose of which was to investigate the degree to which short term radon fluctuations may affect the validity of the grab sampling determination of radon release. These measurements and their interpretation are presented in Appendix C.

The important results from the continuous radon sampling at four mines were the following:

- A diurnal cycle occurs which shows an increased radon release with decreasing barometric pressure. The peak release precedes the time of minimum pressure.
- Although the peak to average ratio for radon over a period of 10 days was as large as 2 in one mine sampled, the high value occurred at a time of an unusually low barometric pressure. A typical range of peak to average of 1.2 to 1.5 was recorded. Ratio of minimum to average ranged from about 0.7 to 0.9. Peak concentrations occurred over relatively short periods, and concentrations near the average were present a much longer fraction of the day.
- The data from continuous monitoring for radon is limited to periods of up to one month at any given mine for a total of four vents from three mines. Hence, we do not have enough data to establish a valid correction factor to account for barometric pressure changes or time-related parameters.

RADON FROM WASTE PILES AT MINES

Radon exhalation from waste piles seven mines was determined from the surface area, an assumed uranium content, and a specific diffusion rate for radon of 0.092 Ci/(m^2·yr·% U_3O_8). Waste piles were characterized in Table 2 (page 16). The contribution of radon from these seven mines is shown in Table 7.

TABLE 7. Estimated Radon Emissions from Seven Mine Waste Piles

Mine	Radon, Ci/yr	Radon Ci/yr in Ventilation Air	Ratio: Ci from Waste / Ci from Ventilation Air
V	26	1010	0.026
EE	16	6,500	0.0025
E	82	29,800	0.0028
H	76	15,200	0.0050
FF	20	2,510	0.0080
G	166	1,800	0.092
F	92	9,400	0.0098
TOTAL	476	66,220	Ave. 0.021

$$\frac{\Sigma \text{ Ci radon from waste piles}}{\Sigma \text{ Ci radon in ventilation air}} = 0.0072$$

In the last column is shown the ratio of curies from waste to curies in ventilation air for the respective mines. The large variation in this ratio represents differences in mine characteristics and waste disposal practices. For mine G this ratio is very large, 0.092, and contributes more weight to the average than all of the other six mines combined.

Mine G is a relatively young mine with relatively low radon in ventilation air, yet with a large waste volume. If this mine were excluded, the average ratio for the remaining six mines would be 0.009, and the ratio of the total curies from waste to total curies in ventilation air for the six mines would be 0.005. The representativeness of the six or seven mine waste areas for the whole industry is not known with assurance; however, the relative contribution of radon from waste piles compared to ventilation air emissions is very small. Inaccuracy in this number would not affect the total release greatly since radon in ventilation air is so predominant as a source. If the average of the seven mines is used, the contribution of radon from waste piles would be about two percent of that in ventilation exhaust.

At the end of mine life the accumulated waste will continue to exhale radon unless the waste is stabilized with soil, is processed through the mill, or is returned to the mine. Table 4B, page 28, gives the extrapolation of the waste pile surface area to the end of mine life taken to be 30 years. In Table 8 is shown our estimate of radon release per metric ton of U_3O_8 taken from the mine during the mine lifetime. Considering the variability of the waste pile configuration and the extrapolation process to derive this estimate, the average is only an approximate indicator of the industry average.

TABLE 8

Estimated Radon Emission from Waste Piles at Four Mines Following Closure of the Mines

Mine	Radon Emissions Ci/yr · metric ton U_3O_8
V	0.041
E	0.016
H	0.040
G	0.035
Average =	0.033±0.006 (Std. dev. of Ave.)

RADON FROM ORE PILES AT MINES

Table 5, page 29, gives the description of ore piles for six mines where ore is currently stored near the mine. Table 9 shows the calculated radon which is released from the ore.

We show the radon from each ore pile normalized to the radon in ventilation air in the last column, giving an average ratio of 0.0039. If the six mines are taken as a composite mine, the ratio would drop to 0.0012. We have chosen 0.004 as the fraction of ventilation air radon which is released from ore piles at the mine, giving what is very likely a conservative value.

RADON DISCHARGED WITH MINE WATER

An estimate was made of radon discharged with pumped mine water using the excess radon determined for water samples from six mines (Jackson et al. 1980). Table 10 shows the data.

TABLE 9. Estimated Radon Emissions from Six Mine Ore Storage Piles

Mine	Radon Ci/yr	Ci/yr in Ventilation Air		Ratio: Ci from Ore / Ci in Ventilation Air
V	5.2	1,010		0.0051
EE	8.9	6,500		0.0014
E	6.9	29,800		0.0002
H	4.8	15,200		0.0003
FF	(No ore storage)	2,510		--
G	24.4	1,800		0.014
F	23.4	9,400		0.0025
	Σ = 73.6	Σ = 66,220	Ave.	0.0039

$$\frac{\Sigma \text{ radon from ore piles}}{\Sigma \text{ radon in ventilation air}} = 0.0012$$

TABLE 10. Estimated Radon Release in Mine Water from Six Mines

Mine	Radon[1] (pCi/ℓ)	Water (gpm)	Radon in Mine Water (Ci/yr)	Radon in Vent. Air (Ci/yr)		Ratio: Ci in Water / Ci in Vent. Air
B	670	1,630	2.2	4,500		0.0005
C	260	305	0.2	4,600		0.00004
F	220	345	0.2	9,400		0.00002
J	310	920	0.6	7,900		0.00008
K	830	1,605	2.7	6,400		0.0004
G	250	220	0.1	1,800		0.00006
					Ave.	0.0002

---

1. Radon in excess over that in equilibrium with ^{226}Ra present

We conclude from these estimates that the quantity of radon released from mine water at discharge will be of little significance compared to other sources of radon release. The subsequent release to the atmosphere of radon from radium in discharged mine water is not addressed in this study. The dissolved fraction will determine the availability of radon for immediate release to the atmosphere. Mode of water treatment for radium removal before discharge to streams or other disposal would determine the availability of radon for release to the atmosphere subsequent to disposal.

RELATIONSHIP OF RADON RELEASE AND U_3O_8 PRODUCTION

The total radon release from operation of the 27 mines sampled in this study is as follows:

Radon in Ventilation Air = 150,000 ± 3000 Ci/yr

Radon from Waste Piles (taken to be 0.02 x radon in ventilation air) = $\sim$3,000 ± 1500 Ci/yr

Radon for Ore Piles (taken to be 0.004 x radon in ventilation air) = $\sim$600 ± 300 Ci/yr

Radon credit for covering natural soil surfaces normally enamating radon (waste and ore piles) = $\sim$(40) Ci/yr

Radon released on discharge of mine water on surface (taken to be 0.0002 x radon in ventilation air. Excludes radon in equilibrium with ^{226}Ra dissolved in water.) = $\sim$30 ± 30 Ci/yr

TOTAL 153,590 ± 3400 Ci/yr

The annual (1978) production given to us by the DOE Grand Junction Office for these mines was 5,760 tons U_3O_8. The radon per ton of U_3O_8 was thus 26.7 Ci/ton or 29.4 Ci/metric ton. With an assumed RRY of 182 metric tons, the radon release per RRY is 5,350 Ci. This would round to 5400 Ci.

Following mine closure and assuming that waste piles remain unstabilized the yearly release of radon from this source will be approximately 0.03 Ci/(yr· metric ton U_3O_8) (Table 8). For one RRY (182 metric tons) 6 Ci radon per year would continue to be released.

Statistics showing the relationship between radon release and mine production for mines sampled and for which we have annual and cumulative individual mine production are shown in Table 11.

Eighteen mines are listed in Table 11 for which 1978 U_3O_8 production was obtained and 15 mines are shown with the cumulative radon release based on entries in Table 6 and the small correction for radon contribution from waste and ore piles and water discharged discussed in the foregoing sections. The data have been rounded to the nearest 100 Ci/yr. Column 4 shows the radon emission per ton of U_3O_8 produced. These entries give clear evidence of the wide variability in the radon emission per unit of current production. The radon emission per ton of U_3O_8 produced in 1978 ranges from 5 to 300 Ci/ton. Converted to Ci/RRY (182 metric tons) the range would be from 1000 Ci/RRY to 55,000 Ci/RRY. The estimate of 3340 Ci/RRY reported for seven mines in the first report of this study (Jackson et al. 1979) is well within the range shown in Table 11.

We have examined the data for the seven mines sampled in 1978 and find that radon emissions have increased very little. At the time of our 1978 measurements we could obtain current production for only two of the mines. Data used for the remainder of the mines were estimates made by mine operators in 1976. A source of uncertainty in arriving at an annual production estimate when the statistic is given in production per day is the number of mine operating days per year. Mine owner production data indicated to have been based on 365 days operation, and used as such in the interim report (Jackson et al.1979) was subsequently found to be based on actual mine working days. For the current report we have used the mine-reported daily production and actual mine operating days to estimate annual production. The composite Ci/RRY will not be affected by any ambiguity about the production day basis since the composite production was furnished by the Grand Junction Office in terms of tons/yr.

TABLE 11. Relationship Between Radon Emission and Mine Production

Mine	Radon(1) Emission (Ci/yr)	U_3O_8(3) 1978 Produced (ton/yr)	Ci Radon/ton U_3O_8 (Ci/ton)	Cumulative(4) Ore Production Through 1978 (10^6 ton)	Radon Emission Rate Per Cumulative Ore Production (10^{-6} Ci/yr-ton)
A	7600	1040	7		---
B	4600	430	11	1.2	3800
C	4700	500	9	1.8	2600
D	3700	530	7	1.5	2500
E(2)	30,000	410	73	3.9	7700
F(2)	9500	340	28	4.7	2000
G(2)	2000	350	6	0.45	4400
H(2)	15,300	120	120	2.6	5900
I	1700	92	19	1.8	960
J	8100	170	48	2.4	3400
K	6600	420	16	1.4	4700
L	1400	35	41		---
R	15,200	51	300	3.0	5100
T	1900	220	9		---
U	900	190	5	0.37	2500
V(2)	1000	50	7	0.15	6900
Y	18,000	1000	18	2.4	7500
Z+CC	4900[5]	170	29	1.6	3100

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1. Radon in ventilation air, from mine waste piles, ore piles, and mine water discharged at surface. Basis: 1.025 x radon in vent. air. (See note 2)

2. For these mines, the contribution of radon from mine waste and ore piles was that estimated from pile dimensions and U_3O_8 content.

3. Based on operator-reported daily ore production, ore grade and mine operation of 250 days/yr, or the number of days operation of the mine reported by mine operators. Values are rounded to two significant figures.

4. Data furnished by mine operator.

5. Production from mines CC and Z were composited by the mine operator. Thus, we have composited their radon output for comparison.

In Table 11 we have also shown the cumulative production from 15 mines which were sampled and for which cumulative ore estimates were avilable. Radon emission per ton of cumulative ore is shown in the last column.

The radon emitted from a mine could be postulated to be related to the total production from a mine since the surfaces which emit radon get larger as ore is removed from the mine. This assumption was examined for the few mines studied in 1978 and a high degree of correlation was found (Jackson et al. 1979).

The relationship between radon emission and cumulative tons of production for the 15 mines of Table 11 is shown in Figure 9.

The least squares linear regression line representing the data for fifteen mines and the 95% confidence intervals for the slope are shown in Figure 9. The line was constrained to pass through the origin, (no intercepts) since it would seem that radon release would commence as soon as ore was produced. The r^2 value of 0.53 indicates that about half the variability could be accounted for by the relationship between radon release per year and accumulative ore production. The correlation is significant, but not highly significant. Variations of the individual mines from the best fit line may have been reduced if contributions from secondary factors which influence radon emission rate could have been taken into account. For example, a particular mine might have been excluded altogether from the correlation because of some unique characteristic, such as having positive pressure ventilation which could affect radon release. Ventilation practices and bulkheading of mined-out areas may alter radon emission rate.

At the present time we have not completed the evaluation of these possibilities of development of an effective model capable of relating emissions to mine characteristics. This will require considerably more detailed study of emissions than has been possible to date.

SUMMARY OF ESTIMATES OF MEASUREMENT ACCURACY AND PRECISION

We have examined the sources and magnitude of errors in the terms to calculate the curies of radon released per RRY. As earlier mentioned, the analysis of variance performed on grab sampled ventilation air emissions could not reveal all error terms because of the limited sampling program at each mine and the practicality of scheduling field collection times. We did not have enough information for a sophisticated and rigorous statistical analysis of all errors. We did have enough additional data to permit some simple descriptive statistics to be used. The details of those procedures are given in Appendix C. We have summarized the sources and estimated the magnitude of uncertainties in the respective quantities measured or otherwise determined. Some sources of error identified as being less than one percent are not included in generating the net error because of their relative insignificance. The remaining errors are considered in terms of their relative standard deviations. In addition to precision terms we have also considered residual biases which we did not attempt to remove from the measurements.

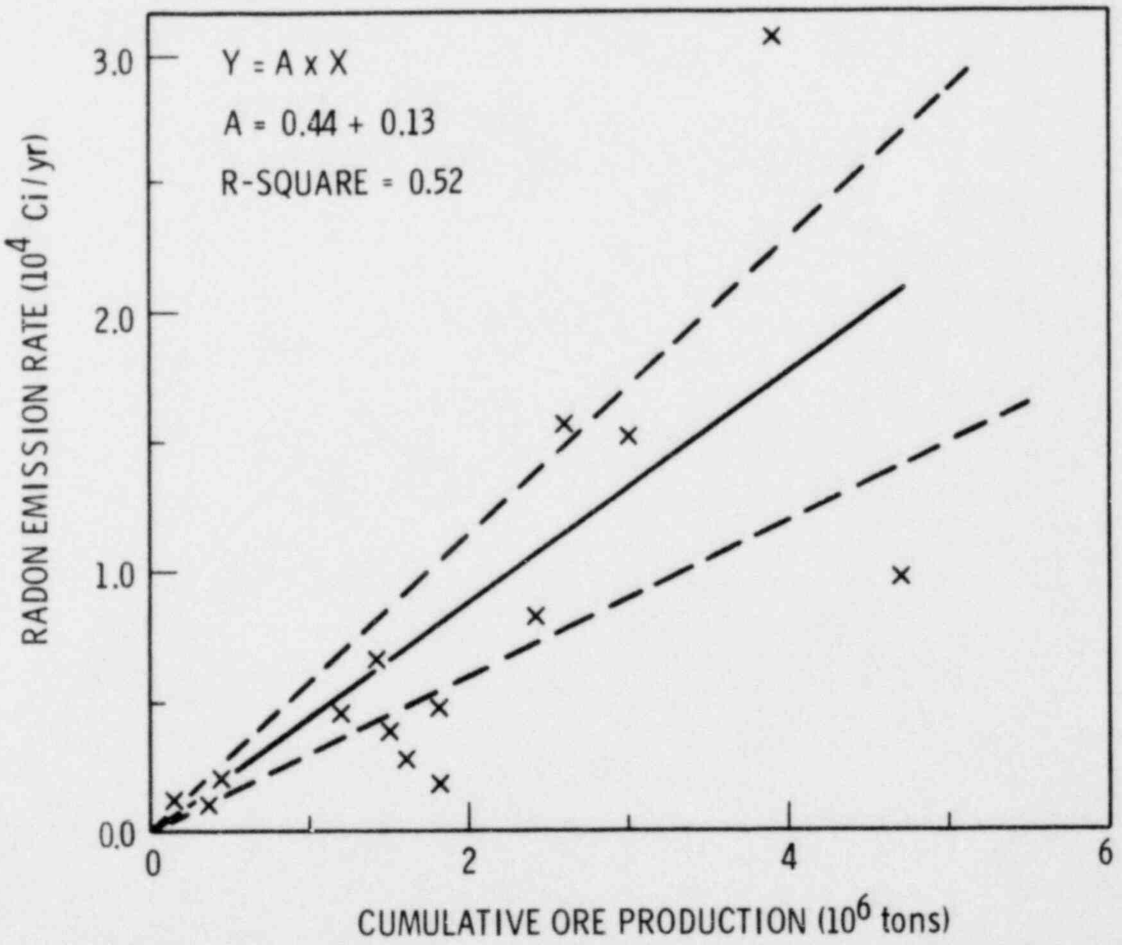

FIGURE 9. Relationship of Annual Radon Emission Rate to Integrated Mine Production

The sources and magnitude of these error estimates are summarized as follows:

Time errors in counting:	< 1%
Time errors for decay corrections:	< 1%
Measurement errors	< 1%
Counting instrument calibration:	1.5%
Estimation of non-ventilation air sources of radon (above-ground sources)	± 2%
Production rate estimate	± 5%
Possible residual bias from short-term variation in radon concentrations (our grab sampling time not coinciding with the time of average concentration) direction unknown	± 5%
Possible positive bias from long-term positive drifts of the radon emission rate	+ 6%
Possible bias in vent flow measuring instruments (direction of bias unknown)	± 7%
Uncertainties in flow measurement due to non-uniform flow	± 1%
Short term flow variations	± 2%

Ignoring the contributions from the errors that are less than one percent, the next three errors listed combine to produce a root mean square estimate of 6% relative standard deviation in our Ci/RRY estimate. Expressed as a 2σ limit (approximately the 95% confidence band) the 6% relative standard error would be 12% based on our estimates of precision. The remaining errors identified as biases may be combined linearly with the precision-related 95% limit to yield an overall uncertainty of +30%/-18%. This appears to be overly conservative since a portion of the estimated bias of 6% resulting from long term radon emission shifts certainly includes effects from short term variations, the influence of weather patterns and measurement errors. Using a more realistic root mean square combination of all these error terms, we obtain a relative standard deviation of ± 12% and an upper limit of ± 24%.

CONCLUSIONS

The radon release from underground uranium mines reported in this study is dominantly from the ventilation air exhausted above ground. This source was measured in 27 mines, representing about 63% of the U.S. production from underground uranium mines. Radon from waste and ore piles at the mine and radon discharged in mine water are relatively insignificant sources -- combined, they represent less than 3% of the radon in ventilation air. The estimated curies released per unit production is highly variable from mine to mine, as might be expected, due to the wide differences in mine parameters which influence radon release. This variability reflects directly into the curies per RRY for each mine. Compositing all radon per year from all mines measured and relating this to all production during the year is the best way to arrive at an industry average of Ci/RRY which, from the mines measured in this study, was 5400 Ci/RRY.

At this time in the study, the radon release per year shows a statistically significant linear relationship with cumulative ore production. Unique mine variables, if they could be taken into account, may permit a better correlation with cumulative ore production.

Although grab samples taken without reference to time of day were shown to be justified, fluctuations in ventilation air radon with time of day (barometric pressure) do account for a significant source of error. Additional continuous monitoring data are needed to permit a valid correction to the grab sample results for time of day and barometric pressure, and to narrow the uncertainty of the predicted Ci/RRY.

The study focused on mines in New Mexico, Colorado, and Utah. Radon from mines in Wyoming should be included eventually, since these mines may have differences giving rise to greater or less radon release.

Possible radon emitted from abandoned mine shafts was not included in the scope of this study. Some attention should be given this possible source, even though, in all likelihood, this source would be a relatively small contribution to the radon in ventilation air.

ACKNOWLEDGEMENTS

This study was made possible only through the cooperation of many mine owners. We cannot acknowledge their help individually for the information they furnished, the assistance they offered in the field study, and the permission they granted us to have access to their mine vents. We thank them for their cooperation and patience. We also thank those individuals at DOE Grand Junction, Colorado, who furnished the summed production for a large number of mines. We also acknowledge the help of the Bureau of Mines in Denver, Colorado in calibrating our radon scintillation cells.

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APPENDIX A

ESTIMATE OF PERCENT OF TOTAL UNDERGROUND PRODUCTION REPRESENTED BY MINE SURVEY

Daily ore production rates reported by 24 surveyed underground uranium mines totaled 15,600 tons/day for 250 days/yr. The total annual ore production for the surveyed mines is 3,900,000 tons/yr.

According to the latest published statistics for the U.S. uranium industry (Department of Energy 1979), the total uranium ore production for 1978 was 14,342,000 tons which yielded 18,800 tons of U_3O_8. (This figure does not include 1,400 tons of U_3O_8 produced in 1978 from mine water, heap leach, and in situ leach processes as well as from miscellaneous low-grade ore from old mine dumps.) We estimate that the mines surveyed represent $\frac{3,900,000}{14,342,000}$ x 100% or about 27% of the total ore production from all U.S. mines in 1978.

Of the over 14 million tons of ore produced by U.S. mines in 1978, a total of 6,105,000 tons (43%) was produced by underground mines. This ore production yielded 9,300 tons of U_3O_8. The surveyed mines therefore represent $\frac{3,900,000}{6,105,000}$ x 100% or about 64% of the 1978 receipts from underground mining.

These estimates assume that ore production for 1979 is not too different from 1978 since the survey data were collected in March-April 1979. Industry-wide data for 1979 were not available at the time of preparing the report.

APPENDIX B. SAMPLE CALCULATIONS

CONCENTRATION AND EMISSION RATES FROM VENTS

The concentration of Radon-222 in vent exhaust is calculated as follows:

$$pCi/_{\ell} = (\text{Gross Counts/min} - \text{background counts/min}) \times \text{Counter Calibration Factor} \times e^{\left(\frac{\ell n\, 2\, (t_c - t_s)}{3.8235}\right)} \qquad (B.1)$$

where the counter calibration factor is the pCi/ℓ per counts/min for our scintillation system; the half-life of Radon-222 is 3.8235 days and $t_c - t_s$ is the elapsed time between the midpoints of the counting period and sampling time in unit of days. For the sample collected from Mine V, Vent 1 on 8/22/79 at 18:52 and counted for 10 min on 8/23/79 at 15:50 the calculated concentration is (see Appendix D)

$$pCi/\ell = (782.5\text{-}6.0) \times 0.271 \times e^{\left(\frac{\ell n2\ (0.87361)}{3.8235}\right)} = 247.$$

For the same vent, the annual emission rate is

$$Ci/yr = 247\ pCi/\ell \times 1{,}682{,}000\ \ell/min \times 5.26 \times 10^{5}\ min/yr \times 10^{-12} Ci/pCi = 219.$$

CURRENT EMISSION FROM ABOVE-GROUND WASTE STORAGE

Waste pile emissions are determined from the pile surface area. The available information about most waste piles included area of the base, the thickness, the U_3O_8 content, and weight (see Table 3). Assuming that these piles are frustrums of pyramids with square bases and sides sloping 30° from the vertical, the surfaces exposed to air are the sides and top. The lateral surface area equals:

$$\frac{\text{top perimeter + base perimeter}}{2} \times \text{slant height} \qquad (B.2)$$

where the slant height = $\frac{\text{pile thickness}}{\cos 30°}$; (B.3) the base perimeter = 4 $\sqrt{\text{base area}}$; and (B.4)

the top perimeter = 4[$\sqrt{\text{base area}}$ -2 x thickness x tan 30°]. (B.5)

The top area of the pile equals

$$(\sqrt{\text{base area}} - 2 \times \text{thickness} \times \tan 30°)^2. \quad \text{(B.6)}$$

For Mine V of Table 3 the waste pile surface area is calculated as follows:

Slant height = 15.3 ft/cos 30° = 17.7 ft

Base perimeter = 4 $\sqrt{89250 \text{ sq. ft.}}$ = 1195 ft

Top perimeter = 4 [$\sqrt{89250 \text{ sq. ft.}}$ -2 x 15.3 ft x tan 30°] = 1124 ft

Lateral surface area = $\frac{1124 \text{ ft} + 1195 \text{ ft}}{2} \times 17.7 \text{ ft} = 20{,}523 \text{ ft}^2$.

Top surface area = $(\sqrt{89250 \text{ sq. ft.}} - 2 \times 15.3 \text{ ft} \times \tan 30°)^2 = 79{,}006 \text{ ft}^2$.

Total surface area = 20,523 + 79,006 = 99,529 ft^2 or 9246 m^2

The current radon emissions from waste piles is calculated by

$$\text{Ci/yr} = \text{Surface area, m}^2 \times 0.092 \frac{\text{Ci}}{\text{m}^2 \cdot \text{yr} \cdot \% \text{ U}_3\text{O}_8} \times \% \text{ U}_3\text{O}_8 \text{ in waste.} \quad \text{(B.7)}$$

Using Mine V as the example, the current emissions from waste piles are

$$9246 \text{ m}^2 \times .092 \frac{\text{Ci}}{\text{m}^2 \text{yr} \% \text{ U}_3\text{O}_8} \times 0.031 \% \text{ U}_3\text{O}_8 = 26.4 \text{ Ci/yr.}$$

For Mine G where the waste pile base was rectangular, the emission rate was calculated using slightly modified equations.

PREDICTED EMISSIONS FROM WASTE PILES AT MINE CLOSURE

The waste pile dimensions at the end of mine life are based on extrapolating the current waste volume to the volume at age 30 years, using the daily ore production and the ratio of ore to waste for the mine. Where the waste production rate was not known, an average ratio of 7.3 was used, which represents a composite of 7 mines of known waste production rate.

Pile Volume at Closure =

Current waste pile volume + (30-current age)(daily ore production) (working days per year)(specific volume) ÷ (ore/waste ratio) (B.8)

The current pile volume is calculated from the thickness and surface area by

$$\text{Volume} = \frac{\text{thickness}}{3}\left(\text{Base Area} + \text{Top Area} + \sqrt{\text{Base Area} \times \text{Top Area}}\right) \quad (B.9)$$

Using Mine V as an example, its current waste pile volume is

$$\frac{15.3}{3}\left[89{,}250 + 79{,}006 + \sqrt{89{,}250 \times 79{,}006}\right] = 1.29 \times 10^6 \text{ ft}^3.$$

At 30 years the Mine V waste pile volume is estimated to be

$$1.29 \times 10^6 + (30-2)(550)(250)(21.4) \div 7.3 = 1.257 \times 10^7 \text{ ft}^3$$

Pile thickness at 30 years is assumed to be determined by mining company practices and the space available for pile expansion. In the case of Mine V the same mining company has two mines that are 21 years of age with an average waste pile thickness of 21.5 ft. Substituting Equation B.6 for the top area in Equation B.9 yields the following relationship of pile volume to base area, b, and thickness T

$$\text{Volume} = bT - 2\sqrt{b}\,T^2 \tan 30° + \frac{4}{3}T^3 \tan^2 30° \quad (B.10a)$$

Letting

$$A = \sqrt{b}$$

$$\text{Volume} = A^2T - 2AT^2 \tan 30° + \frac{4}{3}T^3 \tan^2 30° \quad (B.10b)$$

which allows a solution for the base area using the quadratic equation. In the case of Mine V where the estimated volume at mine closure is 1.26×10^7 ft^3 and the pile thickness is 21.5 ft the estimated base area at closure becomes 6.04×10^5 ft^2.

Using the formulas developed in Appendix A.2 the following are the key dimensions of the Mine V waste pile at 30 years of age or closure:

Slant height = 21.5/cos 30° = 24.8 ft.

Base perimeter = $4\sqrt{604{,}000} = 3108$ ft

Top perimeter = $4[\sqrt{604{,}000} - 2 \times 21.5 \times \tan 30°] = 3009$ ft.

Lateral Surface Area = $(3108 + 3009) \times 24.8/2 = 75{,}900\ \mathrm{ft}^2$

Top Area = $(\sqrt{604{,}000} - 2 \times 21.5 \times \tan 30°)^2 = 566{,}000\ \mathrm{ft}^2$.

The total of the lateral and top surface areas will then be 641,900 ft^2 or 59,600 m^2. The radon emission from the Mine V waste pile after 30 yr of operation is predicted to be about:

$$59{,}600\ \mathrm{m}^2 \times 0.092\ \mathrm{Ci}/(\mathrm{m}^2 \cdot \mathrm{yr} \cdot \%\ U_3O_8) \times 0.031\%\ U_3O_8 = 170\ \mathrm{Ci/yr}.$$

RADON EMISSIONS FROM SOIL COVERED BY WASTE PILES

The waste piles prevent the emission of radon from the normal soil which they cover. An estimate of the emissions prevented can be made using equation B.7 and assuming the normal soil contains 0.0004% U_3O_8. In the case of the current waste pile at Mine V the radon emission prevented is

$$89{,}000\ \mathrm{ft}^2 \times \frac{0.092\ \mathrm{Ci}}{\mathrm{m}^2 \cdot \mathrm{yr} \cdot \%\ U_3O_8} \times 0.0004\%\ U_3O_8 \times \frac{\mathrm{m}^2}{10.764\ \mathrm{ft}} = 0.3\ \mathrm{Ci/yr}.$$

This quantity must then be subtracted from the total waste pile emission of 26.4 Ci/yr yielding a net emission rate from waste of 26.1 Ci/yr.

Similarly, the area covered by waste at the end of 30 yr for Mine V would have emitted 59,600 x 0.092 x 0.0004 = 2 Ci/yr. Thus, the net emission from waste credited to the mine operation at 30 yr of age would be 170-2 or 168 Ci/yr.

RESIDUAL WASTE PILE RADON EMISSION PER PRODUCTION UNIT

The lifetime U_3O_8 production from a mine may be estimated from the reported daily ore production rate, number of production days per year, ore grade, and expected mine life as follows:

$$\text{Lifetime } U_3O_8 \text{ tonnes} = \frac{\text{tons}}{\text{day}} \times \frac{\text{grade \% } U_3O_8}{100} \times \frac{250 \text{ production day}}{\text{yr}}$$

$$\times \frac{0.9072 \text{ tonne}}{\text{ton}} \times \text{yr mine life}$$

In the case of Mine V the estimated lifetime production is then

$$550 \times \frac{0.11}{100} \times 250 \times 0.9072 \times 30 = 4116 \text{ tonnes } U_3O_8.$$

The waste pile emission after mine closure can be expressed in terms of Ci/yr per tonne U_3O_8 produced. For Mine V that value is estimated as

$$\frac{170}{4116} = 0.04 \quad \frac{\text{Ci}}{\text{yr} \cdot \text{tonne}}$$

before correcting for radon suppressed by covering the ground.

RADON EMISSIONS FROM ORE STOCKPILE

The radon from ore stockpiles is based on the radon production from radium which is assumed to be present in equilibrium with the uranium in the ore. Twenty per cent of the radon produced is assumed to be available for emission. The average weight of the ore stockpile is based on half the stockpile tonnage accumulated before shipment to the mill. This quantity will depend on the daily production rate and the frequency of haulage as follows:

$$\text{Average Ore Stockpiled} = 0.5 \times \text{Daily Production} \times 5 \text{ work days/wk} \times \text{Haulage Interval}.$$

At Mine 1 where the daily production is about 550 tons and the stockpile is hauled to the mill weekly, this calculates to 1,375 tons ore in the stockpile on the average.

The production rate of radon atoms equals the decay rate of radium atoms which in turn equals the decay rate of U-238 atoms at equilibrium. The equation for radon formation per year per ton of ore is

$$\text{Atoms Rn/(yr}\cdot\text{ton)} = \frac{9.072 \times 10^5 \text{ g}}{\text{ton}} \times \frac{0.0011 \text{ g } U_3O_8}{\text{g ore}} \times \frac{0.848 \text{ g U}}{\text{g } U_3O_8}$$

$$\times \frac{7.47 \times 10^5 \text{ d U-238}}{\text{min}\cdot\text{g U}} \times \frac{5.26 \times 10^5}{} \frac{\text{min}}{\text{yr}}$$

$$\times \frac{1 \text{ atom Rn-222}}{\text{d U-238}} = 3.325 \times 10^{14}$$

where d = disintegrations.

For Mine V the average production rate of radon in the stockpile is then

$1375 \times 3.325 \times 10^{14} = 4.57 \times 10^{17}$ atoms per year. The decay rate for radon is calculated as

$$\begin{array}{l} \text{Formation Rate} \\ \text{(Curies/yr)} \end{array} = \text{(Atoms/yr)} \times \frac{\text{decay constant/min}}{2.22 \times 10^{12} \text{ d/min}\cdot\text{Ci}} \qquad \text{(B.11)}$$

$$= \text{(Atoms/yr)} \times \frac{1.259 \times 10^{-4}\text{/min}}{2.22 \times 10^{12} \text{ d/min}\cdot\text{Ci}}$$

$$= \text{(Atoms/yr)} \times 5.671 \times 10^{-17} \text{Ci/d.}$$

Thus, for Mine V the radon formation rate is

$$4.57 \times 10^{17} \times 5.671 \times 10^{17} = 26 \text{ Ci/yr.}$$

Assuming 20% of the radon is available for emission, the annual emission rate from the ore stockpile at Mine 1 is estimated to be about 5.2 Ci/yr.

RADON DISCHARGED WITH MINE WATER

In calculating radon emission due to mine water discharge we assumed that all the radon, in excess of the amount in equilibrium with the Ra-226 in the water, is released when the water is exposed to atmosphere upon discharge. The data for excess radon in water was determined for the mines listed in Table 10 (Jackson et al. 1980). The discharge rate of mine water was supplied by mine operators. The radon in mine water is calculated by

$$^{222}\text{Rn Ci/yr} = \frac{\text{pCi}}{\ell} \times \frac{\text{gallon}}{\text{min}} \times 5.26 \times 10^5 \frac{\text{min}}{\text{yr}} \times \frac{3.785\ \ell}{\text{gallon}} \times \frac{\text{Ci}}{10^{12}\text{pCi}} \qquad (B.12)$$

In the case of Mine B where the radon concentration was 670 pCi/ℓ and the rate of water discharge was 1,630 gal/min the annual radon release from this source was

$$670 \times 1630 \times 5.26 \times 10^5 \times 3.785 \times 10^{-12} = 2.2 \text{ Ci/yr}$$

APPENDIX C

PRECISION AND ACCURACY

The principal elements in the calculation of ^{222}Rn Ci/RRY are shown in the following equation

$$\text{Ci/RRY} = \text{Counts} \times \text{Elapsed Counting Time}^{-1} \times \text{Counter Calibration Factor} \times \text{Decay Correction} \times \text{Annual Vent Flow} \times \text{Annual Production}^{-1} \times \text{metric tons per RRY} + \text{above-ground Ci/RRY}.$$

To obtain an estimate of the overall error in Ci/RRY, we have examined errors introduced in each term of this expression. Using estimates of the coefficient of variation (standard deviation ÷ average value) of each term, we propagated the errors in a standard way. Throughout this section we have assumed that an upper limit error estimate represents two standard deviations, and thus, a derived standard deviation would be one-half this upper limit bound. Where possible biases could be demonstrated, the biases (expressed as a fraction of the average) have also been treated as relative standard deviations to permit their combination with other error terms. This approach is more practical than analytical. We believe these procedures provide reasonable estimates of uncertainty in the final number, in the absence of more universally accepted techniques for handling such errors. This section discusses error estimates in the elements of the measurements and calculation.

The elapsed counting time and decay corrections (which include an elapsed time factor) are not considered further because their contribution to the overall error is less than 1%.

COUNTS

We consider the counting errors to include both measurement errors (i.e., errors associated with sample analysis) and the variability of the radon concentrations in mine ventilation air. The observed variability in radon concentration is accounted for by both short-term effects (those producing hourly to daily variation) and long-term effects such as might be due to the change of seasons or the development of a mine. Both short- and long-term effects will be discussed separately.

Measurement Errors

An analysis of variance of the grab sample data from 26 mines showed that the relative standard deviation caused by measurement errors averaged 7%. Since most vent emission averages were based on sets of four or more replicate samples, this error is reduced to about $\frac{7}{\sqrt{4}}$ or approximately 4% for the emission measurement at any vent. Summing the emission from all vents of a mine (one to fifteen vents) yielded a standard deviation on the average of 1% to 4% from measurement error. Summing over all 27 mines further reduces the relative standard deviation. A factor of about $\frac{1}{\sqrt{27}}$ would result if all concentrations were the same, giving an overall relative standard deviation of less than 1% for the total emission from the mines sampled. Although the actual error for unequal emission rates would be expected to be larger than this, the actual pattern of emissions would still yield errors on the order of 1% or less, hence errors from this source will not be included in compositing errors.

Short-Term Concentration Variations

From analysis of variance procedures, estimates were obtained for the relative percent standard deviation of grab samples taken at various times from the same vent. These temporal variations for a single vent resulted in an average deviation of 19% with a distribution about the average such that the standard deviation was ±24%. These time-related variations at a single vent were much more significant than measurement errors and had a wider variation about the mean. We used continuous radon measurements to evaluate this source of variation at four mine vents (located in Colorado, New Mexico, and Utah). The measured concentrations are plotted in Figures C.1, C.2, and C.3. The figures show plots of both the raw monitor output data and the corrected radon concentrations to illustrate the effectiveness of the mathematical procedures (Thomas, 1979) for extracting rapid changes in radon concentration from slowly changing counting rates. The local barometric pressures are also shown in these figures for comparison.

FIGURE C.1 Radon Concentration and Barometric Pressure Mine G - 1978

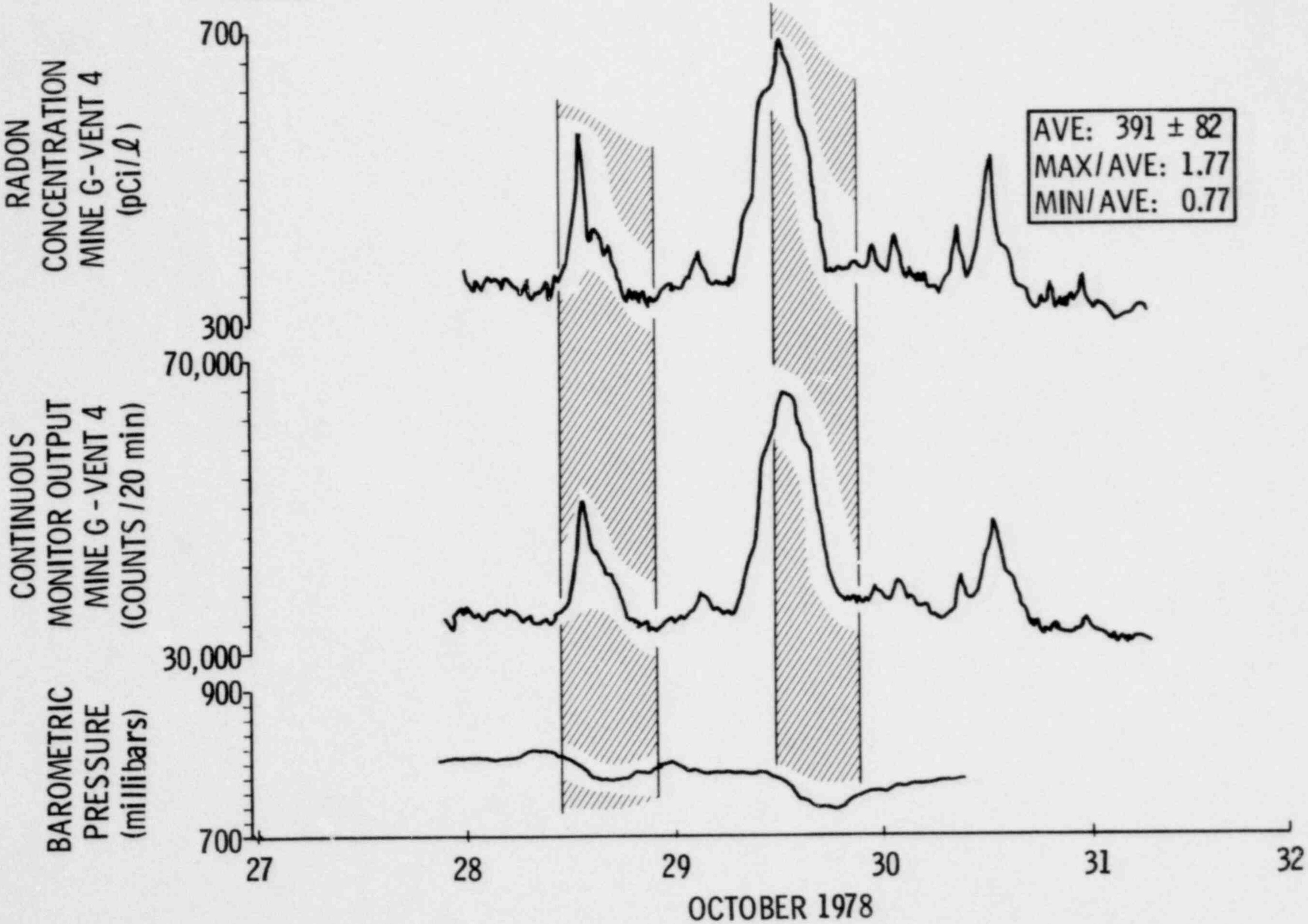


FIGURE C.2 Relationship of Radon Concentrations with Barometric Pressure Mine G - 1979

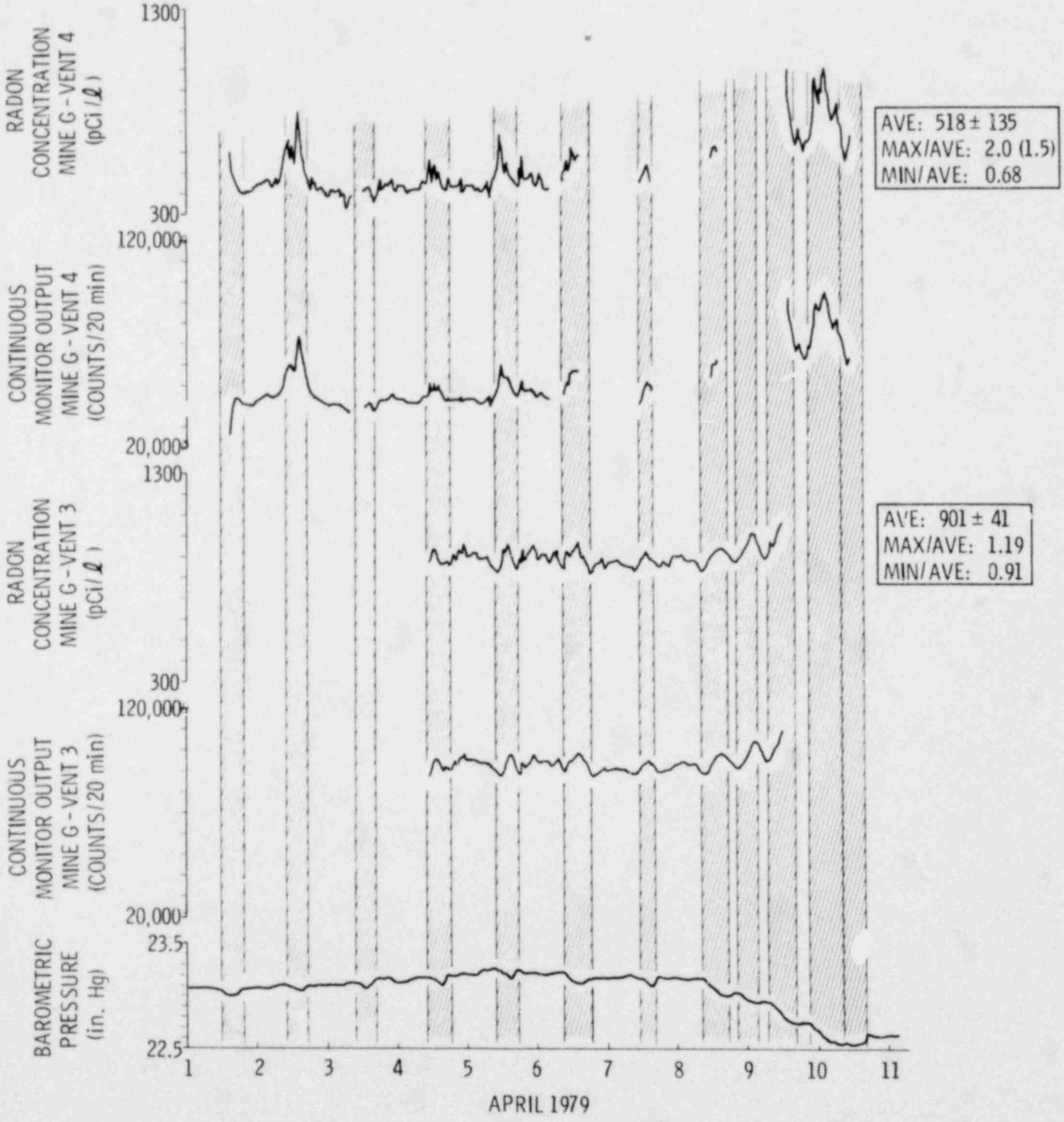
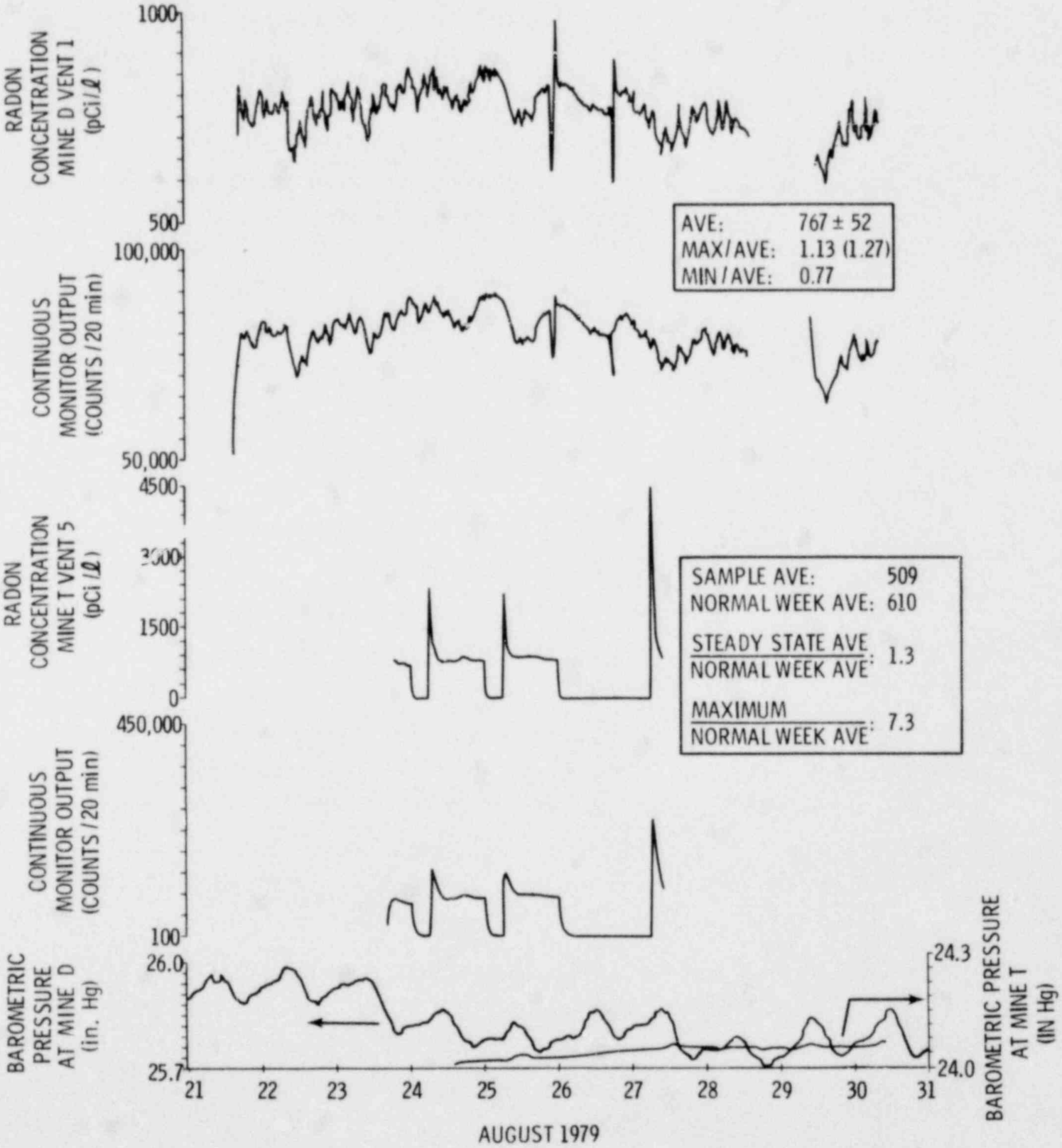


FIGURE C.3 Radon Concentration and Barometric Pressures Mine D and T - 1979



With the exception of Mine T, Vent 5 of Figure C.3 all plotted concentrations are characterized by diurnal variations. Increases in radon concentration tended to occur when the barometric pressure was falling. The intervals during which barometric pressure was below average are indicated by shading in Figures C.1 and C.2.

The figures also indicate the average concentration for each vent and the ratios of both the highest and lowest concentrations to the average. The ratio of the highest concentration encountered to the average varied from 1.2 to 1.5 except for one case where the ratio was 2.0 during a severe low barometric pressure resulting from a local storm. The ratio of minima to average ranged from 0.68 to 0.91. Taking a grab sample during these extremes will yield a biased emission rate. We attempted to evaluate the effect of a number of these biases on a large group of grab samples.

To derive an approximate estimate for these effects we first collated the continuous monitoring data for Mine G, Vent 4 and for Mine D into hourly intervals so that all measurements recorded for a given hour could be averaged. Dividing the average for a given hour interval by the overall average for the data collected during several days operation, we obtain an estimate of the fractional bias for grab samples collected during the given interval.

The fractions of the total curies represented by grab samples collected during each hour were also determined. The products of the bias for each hour and the fraction of the total curies collected per year during that hour were summed to obtain an emission rate weighted bias for our air sampling schedule. Data from these analyses for radon results from two mines are shown in Table C.1.

The average bias and its standard deviation for Mine G was 1.06 ± 0.02 and for Mine D was 0.98 ± 0.004. Thus, the two standard deviation (2σ) upper limit for the bias ranges from a low of 0.97 at Mine D to a high of 1.10 at Mine G.

TABLE C.1

Distribution of Grab Sample Collection Times and Associated Biases

Hourly Interval	Hourly Average Radon Concentration / Overall Average Radon Concentration		Fraction of Total Ci/yr in Grab Samples Taken During Interval
	Mine D	Mine G	
0800 - 0900	1.024 ± 0.010	0.975 ± 0.086	0.0014
0900 - 1000	1.017 ± 0.0012	0.989 ± 0.073	0.038
1000 - 1100	0.978 ± 0.012	1.023 ± 0.055	0.084
1100 - 1200	0.956 ± 0.011	1.022 ± 0.032	0.175
1200 - 1300	0.960 ± 0.011	1.112 ± 0.038	0.059
1300 - 1400	0.979 ± 0.011	1.070 ± 0.033	0.098
1400 - 1500	0.970 ± 0.012	1.049 ± 0.036	0.166
1500 - 1600	0.972 ± 0.012	1.134 ± 0.061	0.200
1600 - 1700	1.003 ± 0.009	1.062 ± 0.063	0.111
1700 - 1800	0.980 ± 0.014	0.979 ± 0.050	0.042
1800 - 1900	0.984 ± 0.015	0.925 ± 0.045	0.012
1900 - 2000	0.956 ± 0.015	0.950 ± 0.046	0.011
2000 - 2100	0.993 ± 0.018	0.930 ± 0.040	0.0028
Weighted Average	0.977 ± 0.004	1.058 ± 0.020	

Neither mine vent can be considered representative of the numerous samples collected in the field, some samples may have been taken with the higher bias and some with the lower, but since these biases tend to cancel, it seems reasonable to conclude that an average of many vents would not be biased any more than the highest of the two calculated above (1.10). If one concludes that the upper limit (2σ) of the sampling bias is between +10% and -10%, the error propagation could be handled similarly to a precision estimate. We thus estimate the equivalent relative standard deviation to be 5%.

The data for Mine T are unique because it was the practice there to turn off the ventilation fans each morning at 7:00 am. The fans were also turned off from 1:00 am Sunday to 7:00 am Monday. These fan operating cycles dominate the radon concentration pattern. When the fans restarted, a peak concentration followed which was more than double the steady state concentration each working day and was even greater after the weekend shutdown. Because we did not monitor during an entire week's cycle of emissions, the normal weekly average concentration was obtained by taking weighted averages of appropriate portions of intervals actually monitored. This normal weekly average is shown in Figure C.4 along with the average for the actual sampled interval. We assumed that the level portion of each day's pattern from 11:20 am to 1:00 am was typical of the steady state emission rate which might be expected if the vent fans were not turned off. Thus, we averaged the data for the 11:20 am to 1:00 am time interval over two working days and compared that average with the average weekly emission rate to check the effectiveness of cyclic ventilation in reducing radon emissions. The steady-state emissions during the 11:30 am to 1:00 am interval were 30% greater than the complete weekly cycle average. This result was not expected because the radon loss which can occur from simple radioactive decay during off times each week is only about 5%. This effect may indicate an error in our assumptions or may indicate that there is a flow of mine air away from the sampled vent during fan shutdown.

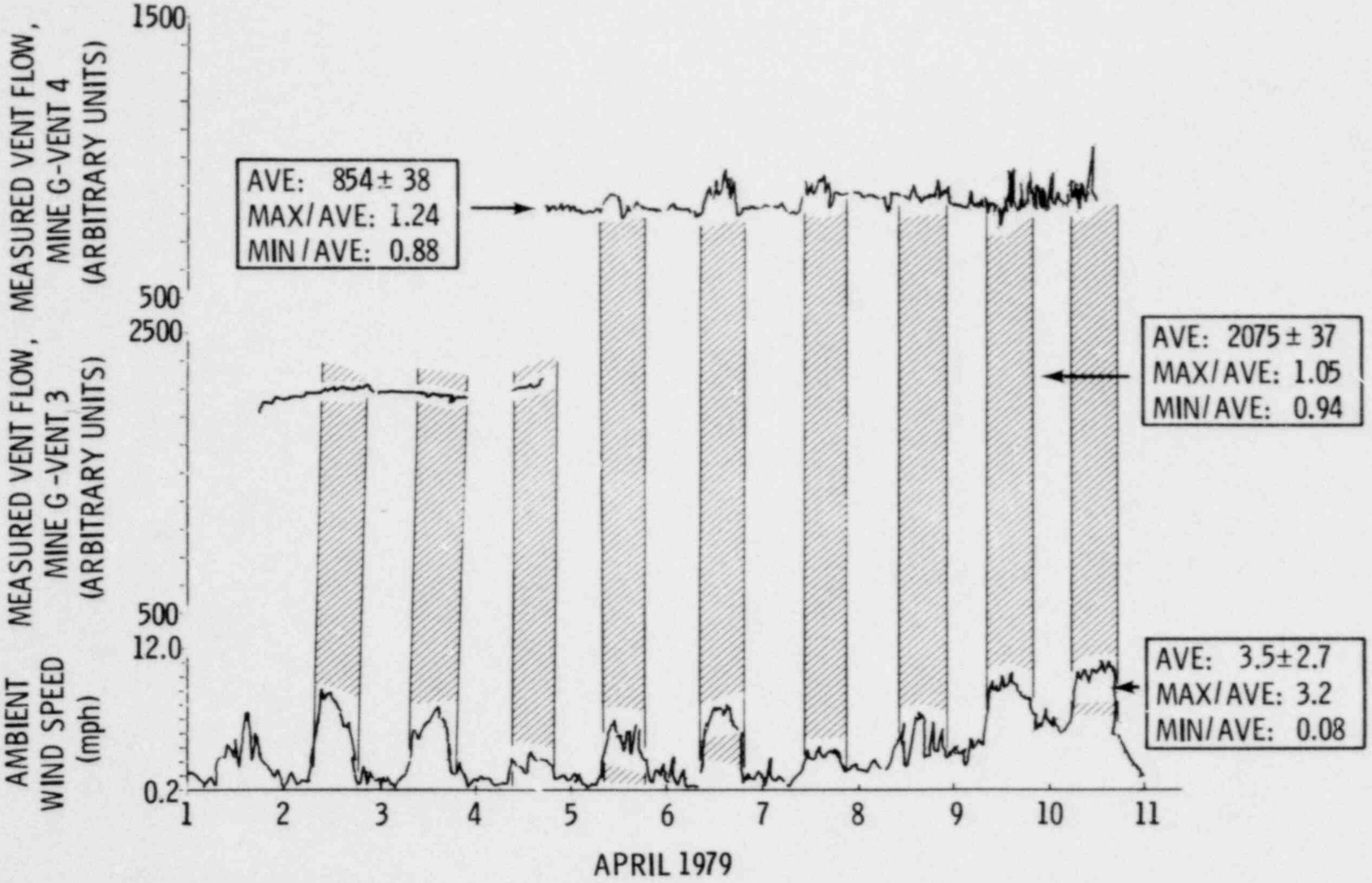


FIGURE C.4 Correspondence of Measured Vent Flow Irregularities with Windy Outdoor Air Periods

Because of the observed cyclic emission pattern at Mine T, we normalized the grab sample results from this mine to the equivalent normal weekly average using the continuous monitor readings at times corresponding to the grab sampling times. The measured mine emission rate was multiplied by a factor of 0.78. The uncertainties introduced by this method of ventilation on our overall (27-mine) emission estimate was neglected because it is not current practice at the other 26 sampled mines to routinely shut down the ventilation of the entire mine.

Long-Term Concentration Variations

The radon emission rates at several mines were measured both in the fall of 1978 and about six months later in the early spring of 1979. On the average, the concentrations were 18% higher in the spring than in the fall. These increases may not be entirely systematic. Mine AA, which saw a 41% increase, is attached to some large inactive mines and part (or all) of the increase could have occurred if the ventilation path were altered so that more air is drawn from the inactive mine to the exhaust vent. Such changes are quite common as mine development progresses. Since only a single sample was collected from Mine AA during 1979, the increase could also have resulted from short-term variations as discussed earlier. It is, however, unlikely that all the occurrences of high ratios resulted from short-term variations.

There is a tendency for the higher increases to occur at the younger mines. This seems to imply that there is a greater change of emission rate when a mine is small and the annual development in the mine is large relative to the size of the mine. It could also imply that rock permeability and radon emanation change during the early stages of mining. We have not pursued modeling of long-term radon emission changes, but in the future we hope to perform long-term continuous measurements at a number of these mines over a sufficient interval to allow differentiation of long- and short-term emission patterns.

Taking January 1, 1979 as the reference time for our measurements, the mine emission rates based on measurements in the fall of 1978 and spring of 1979 should be unbiased by long-term emission changes. Emission rates based on only fall 1978 measurements may be considered 9% low on the average, those based on only spring 1979 measurements can be considered 9% high, and those based on only September 1979 measurements would be about 27% high. Taking an emission rate weighted average of these biases, the average bias from long-term shifts is +6% relative to January 1, 1979. We have made no corrections to emission rates because of this possible bias, but the bias will be taken into account with the measurement errors.

COUNTER CALIBRATION FACTOR

The counter calibrations presented in our previous report, (Jackson et al. 1979) yielded a relative standard deviation of 1%. This cross calibration was traceable to an NBS ^{226}Ra standard with an upper limit error of 1%. The upper limit (two standard deviations) of the total error of calibration is thus 3%, and the relative standard deviation from this source is estimated at 1.5%.

ANNUAL VENT FLOW

Flow rate measurements are subject to error of measurement and errors from the variability of the flow rate with time. In the latter case, we cannot determine such long-term effects as would result from changes in the underground air path or in the fan size. The errors in flow measurement caused by short-term flow variations, instrument precision, and flow irregularities will be discussed and some comparisons with mine operator flow data will be made.

We monitored short-term variation in vent flow for up to a week to determine if flow changed rapidly enough that it could not be considered constant over the few days interval between sample collections. Figure C.4 shows the output of a recording vane anemometer mounted at the mouths of two mine vents in April 1979. Also shown for comparison is the local wind speed for the same period. The anemometer trace was much more variable during windy conditions (indicated by shaded areas) than during calm conditions. This indicated that wind interferes somewhat with vane anemometer measurements when the instrument is used at the vent mouth. At Mine G the

the standard deviations of the measurements were about 4% at Vent 4 and 2% at Vent 3. The true variation in vent flow is probably best derived from the data recorded during calm conditions and we estimate the standard deviation of the flow to be 2%. The uncertainty due to wind interference on vane anemometer measurements is not considered further because its contribution to grand total ventilation air flow for the 27 mines is mitigated by the fact that not all flow measurements were made by vane anemometer and of those that were, not all were made under windy conditions.

In Tables C.2 and C.3 are summarized the cases where flow rates were measured with different instruments and at different times by both PNL and mine operators. Table C.2 shows that in two cases the agreement was good between two vane anemometers from the same manufacturer. The table also shows that vent flows measured with these vane anemometers were usually biased higher than when a pitot tube was used. The highest ratio of vane anemometer to pitot tube flow measurements was 1.14 (when both measurements were made by PNL) for a highest potential bias of 14 percent. Because this is the highest bias from using the vane anemometer method and the biased flow measurements are combined with unbiased measurements for other vents in computing the overall number of emitted curies, we estimate the average potential bias to be about one-half times 14% or 7%. Since either of the instruments could have been affected by the non-standard field conditions, the direction of this bias is uncertain and we have carried the error as ±7% in our calculations.

In some instances we were unable to make our own measurements of vent flow and we used the mine operator's measurements. To determine what impact this might have on our error estimate, we compared some cases where measurements were made by both mine operators and PNL, although the measurements were not made on the same date. These data are shown in Table C.3. We found that the average bias between our measurements and the mine operator's were the same as between our own instruments. No significant additional bias could then be demonstrated by this comparison.

TABLE C.2

INTERCOMPARISON OF VENT FLOW MEASUREMENTS USING DIFFERENT INSTRUMENTS

LABORATORY	PNL		PNL		PNL		PNL		MINE OP		MINE OP		
INSTRUMENT	V_1		V_2		V_3		P		P		P		RATIO OF MEASUREMENTS
	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	
	4-79	41.0*				38.4							$V_1/V_3 = 1.07$
	4-79	58.4					4-79	52.1					$V_1/P_{PNL} = 1.12$
	4-79	73.1	4-79	71.3									$V_1/V_2 = 1.03$
	4-79	77.1	4-79	77.6									$V_1/V_2 = 0.99$
			4-79	92.3	4-79	84.4	4-79	86.2	4-79	93.3			$V_2/P_{PNL} = 1.07, V_3/P_{PNL} = 0.98,$ $P_{PNL}/P_{M-1} = 0.92$
			4-79	123.9 (110.1)	4-79	103.1	4-79	96.4	4-79	102.9	4-79	100.0	$V_2/P_{PNL} = 1.14, V_3/P_{PNL} = 1.07,$ $P_{PNL}/P_{M-1} = 0.94, P_{PNL}/P_{M-2} = 0.96$

P = PITOT TUBE

V_1, V_2 = DAVIS HIGH SPEED VANE ANEMOMETERS

V_3 = WEATHERMEASURE VANE ANEMOMETER

M = MINE OPERATOR

PNL = PACIFIC NORTHWEST LABORATORY

* SINGLE POINT MEASUREMENT, NOT A COMPLETE TRAVERSE

TABLE C.3

A COMPARISON OF VENT FLOW MEASUREMENTS (PNL VS MINE OPERATOR)

LABORATORY		PNL		PNL		PNL		MINE OP.		MINE OP.		MINE OP.		PNL / MINE OP.		MINE OP. / MINE OP.			MINE OP. / MINE OP.		
INSTRUMENT		V_1		V_2		PITOT		PITOT		PITOT		PITOT		DATE	RATIO	DATE	DATE	RATIO	DATE	DATE	RATIO
MINE	VENT	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$	DATE	$10^3 ft^3/m$								
1	1			4-79	12.4			3-79	17.5	4-79	12.4			4-79	1.00	3-79	4-79	1.41			
1	2			↓	15.6			↓	17.1	↓	13.3			↓	1.17	↓	↓	1.29			
1	3			↓	30.8			↓	27.3	↓	27.2			↓	1.13	↓	↓	1.00			
1	4			↓	36.0			↓	21.0	↓	32.9			↓	1.09	↓	↓	0.64			
1	5			↓	62.4			↓	45.0	↓	52.4			↓	1.19	↓	↓	0.86			
2	1					9-78	9.7	9-78	9.0	10-78	9.0			9-78	1.08	9-78	10-78	1.00			
2	2					↓	30.0	↓	28.7	↓	28.7			↓	1.05	↓	↓	1.00			
2	3					↓	79.8	↓	80.1	↓	77.0			↓	1.00	↓	↓	1.04			
2	4					↓	32.9	↓	28.3	↓	29.7			↓	1.16	↓	↓	0.95			
2	5					↓	38.0	↓	34.9	↓	35.3			↓	1.08	↓	↓	0.99			
2	1	4-79	8.2					3-79	9.0	4-79	8.9			4-79	0.92	3-79	4-79	1.01			
2	2	↓	28.3					↓	22.2	↓	23.6			↓	1.20	↓	↓	0.94			
2	3	↓	94.7					↓	79.2	↓	78.5			↓	1.21	↓	↓	1.01			
2	4	↓	42.6					↓	38.0	↓	36.9			↓	1.15	↓	↓	1.03			
3	1					10-78	18.0	5-78	19.9	7-78	20.4	10-78	22.0	10-78	0.82	5-78	10-78	0.90	7-78	10-78	0.93
3	2					↓	75.7	↓	47.3	↓	86.5	↓	89.0	↓	0.85	↓	↓	0.53	↓	↓	0.97
3	3					↓	29.4	↓	30.8	↓	30.8	↓	27.0	↓	1.09	↓	↓	1.14	↓	↓	1.14
3	4					↓	103.9	↓	98.1	↓	93.9	↓	93.0	↓	1.12	↓	↓	1.05	↓	↓	1.01
4	1					10-78	89.3	5-78	93.9	10-78	87.1			10-78	1.03	↓	↓	1.08			
4	2					↓	56.7	↓	14.8	↓	56.5			↓	1.00	↓	↓	0.79			
4	3					↓	95.3	↓	89.5	↓	77.4			↓	1.23	↓	↓	1.16			
4	4					↓	29.7	↓	28.3	↓	40.0			↓	0.74	↓	↓	0.71			

$\text{AVE} \pm \text{S.D.}_{\text{AVE}} \left[\text{PNL-V / MINE OP.} \right] = 1.12 \pm 0.03$

$\text{AVE} \pm \text{S.D.}_{\text{AVE}} \left[\text{PNL-P / MINE OP} \right] = 1.02 \pm 0.04$

V_1 = DAVIS HIGH SPEED VANE ANEMOMETER #1
V_2 = DAVIS HIGH SPEED VANE ANEMOMETER #2
P = PITOT TUBE

An additional source of error in vent flow measurement s nonuniform flow patterns at some vents. In making traverses, one finds sometimes both positive and negative flow in close proximity to each other although there is a large net positive flow. These extreme cases appeared when there were large flow obstructions in the mouth of the vent. In one extreme case where there were vanes in the vent opening (cutting the round opening into wedges like a pie), we made a detailed traverse by finely dividing the spaces in between vanes and averaging the readings. We noted a 16% difference in calculated flow between this technique and a conventional velocity traverse method.

We have assumed such a large discrepancy in measurements was the exception rather than the rule and errors will tend to be in either direction; thus, nonuniform flow assessment contributes roughly a 1% error to the radon emission calculation. This then will be combined with a 2% error from short-term flow variations and a possible 7% bias from instrument errors.

ERRORS FROM ABOVE-GROUND SOURCE TERMS

Radon emissions from above-ground sources were estimated in part from waste pile measurements made by mine operators in five cases and by PNL in two cases. Our measurements were made in one case with a rangefinder and the other case with the odometer of a motor vehicle. The technique used by mine operators is unknown. We assume then that any dimension of the piles was measured to a relative standard deviation of 20%. The error in calculating a surface area would then be approximately 20% $\sqrt{2}$, or about 30%.

The characteristic emission rate per unit area and per percent U_3O_8 used for waste piles is an average value for ore reported by Nielson et al. 1979. The real value can vary depending on the diffusion characteristics of the waste pile and the fraction of radon available for diffusion. Nielson tabulated estimates from a number of authors, and the estimates cover a five-fold range. More recent data collected by PNL show that the radon flux per unit surface is log-normally distributed with a relative standard deviation of +69%, -43%. Since we have not attempted to use log-normal distributions throughout this report, we arbitrarily assign an uncertainty of ±50% to the characteristic emission rate.

Estimates of the grade of waste material were obtained from mine operators. Because their estimate is used to determine the economics of milling the waste and the proportions to use in blending, we believe their estimates to be accurate to a standard deviation of 20%. Where we estimated waste pile U_3O_8 content, we arbitrarily used a value of one-half the current cut-off grade (0.05%) or 0.025%. We assign this estimate a relative standard deviation of 50%. The approximate average of the waste grade uncertainties is then about 40%. The overall variation of our waste pile emissions is then determined from our estimates for dimensional, characteristic emission rate, and grade uncertainties (30%, 50%, and 40%, respectively) as follows

$$100\sqrt{0.3^2 + 0.5^2 + 0.4^2} = 70\%.$$

In the case of ore stockpiles our estimate of frequency of shipment to the mill is an average of data supplied by the mine operators. The shipping frequency can vary because of mill capacity, ore demand, ore production rate, distance to the mill, labor problems, and the weather. This in turn affects the average amount of ore stockpiled on the surface. We will arbitrarily assign a standard deviation of 20% to our estimate of the quantity of ore stockpiled. To our assumption that 100% of the available radon is emitted, we assign a precision of +0%, -50% and for calculation purposes a relative standard deviation of 25%. The fraction of radon available for emission has been reported (Austin 1975) to vary from less than 1% to greater than 90% for ore samples collected in the sampled states. The variation in regional averages reported by Austin (1975) was ±61%, so we will use a conservative ±75% for our calculations. In combining the errors in the emission calculation for ore stockpile, we then have relative standard deviations of 75% for the percentage of radon available for emission, 25% for the estimate of all available radon that is emitted, and 20% for the average quantity of ore. The combined relative standard deviation is then

$$100\sqrt{0.2^2 + 0.25^2 + 0.75^2}$$

or about 80%. Since the emissions from ore and waste piles are an additive term to the expression for Ci/RRY, the propagation of these errors requires weighting by the relative amounts of such emissions.

The radon emissions from the waste piles and ore piles amount to only about 2% and 0.3%, respectively of the total radon emissions. The uncertainties in our estimates of above-ground source terms contribute only about 0.02 x 70% = 1.4% from waste piles and 0.003 x 80% =0.24% from ore piles. These add up to a relative standard deviation of roughly 2% contributed to the total radon emission rate calculation.

PRODUCTION RATE ERRORS

Our estimate for aggregate 1978 production for the mines sampled (5525 tonnes) was furnished by the U.S. Department of Energy. Our contact at the DOE felt the maximum error of the production statistics was about 10%. We assume this to mean than 10% is twice the relative standard deviation which is thus 5%.

ERRORS IN DEFINITION OF RRY

We have not considered in our error estimate any uncertainty in the value of 182 tonnes of U_3O_8 for the annual fuel requirement for a 1000 MWe nuclear power plant (RRY). Any refinement or other adjustment made in this value will reflect proportionately in the Ci of radon/RRY.

OVERALL ERROR

The overall error is a composite of estimated biases and propagated measurement precisions. A part of that error will tend to follow the normal root-mean-square law of propagation, while others may be additive. A summary of the errors discussed in this appendix is shown in Table C.3.

Ignoring those less than 1%, a root mean square (rms) combination of the standard deviations yields a 6% relative standard deviation and a upper limit (2σ) of 12%. Adding the biases to this yields limits of +30%, -18%, which seem overly conservative. Calculating the rms standard deviation, including the biases as a random error, yields a 12% relative standard deviation or upper limit (2σ) of 24%.

TABLE C.4

Summary of Error Sources and Magnitude Estimates

Error Term	Relative Std. Dev.	Relative Bias
Elapsed counting time	<1%	
Decay correction	<1%	
Measurement errors	<1%	
Short-term source variation		±5%
Long-term source trend		±6%
Counter calibration factor	1.5%	
Vent flow instrument error		7%
Nonuniform flow	1%	
Short term flow variation	2%	
Above-ground sources	2%	
Production rate	5%	

APPENDIX D

TABLE D.1

COMPUTER READOUT OF RADON MEASUREMENTS AND INDICATED ANNUAL RELEASE TO THE ATMOSPHERE

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                              DATE.TIME  OF               AIRFLOW      RADON ACT.     RADON CONC.   RADON EMISSION
COUNT   MINE   VENT#    COLLECTION       COUNT            (L/MIN)      (CNTS/MIN)       (PCI/L)      RATE (CI/YR)
--------------------------------------------------------------------------------------------------------------------
   1     A      1.     790425.1434.   790426. 956.       2790000.         3837.          1151.           1688.
   2     A      1.     790425.1432.   790426. 956.       2790000.         3389.          1139.           1670.
   3     A      1.     790430. 947.   790501.1024.       2790000.         3464.          1211.           1775.
   4     A      1.     790430. 949.   790501.1024.       2790000.         4059.          1267.           1857.
   5     A      1.     790817.1543.   790820.1356.        849000.         4710.          2171.            969.
   6     A      1.     790817.1539.   790820.1336.        849000.         4852.          2232.            996.
   7     A      1.     790817.1541.   790820.1336.        849000.         5148.          2358.           1052.
   8     A      2.     790425.1522.   790426.1018.       3140000.         7172.          2401.           3963.
   9     A      2.     790425.1520.   790426. 956.       3140000.         8169.          2483.           4099.
  10     A      2.     790430.1349.   790501.1045.       3140000.         6774.          2302.           3800.
  11     A      2.     790430.1347.   790501.1024.       3140000.         8112.          2504.           4133.
  12     A      2.     790817.1522.   790820.1322.       3143000.         5010.          2297.           3794.
  13     A      2.     790817.1523.   790820.1336.       3143000.         4712.          2172.           3588.
  14     A      3.     790425.1450.   790426. 956.       2440000.         2085.           636.            816.
  15     A      3.     790425.1448.   790426. 956.       2440000.         2115.           650.            834.
  16     A      3.     790430.1107.   790501.1024.       2440000.         1918.           604.            775.
  17     A      3.     790430.1105.   790501.1024.       2440000.         1886.           599.            768.
  18     A      3.     790817.1448.   790820.1300.       2443000.          757.           349.            448.
  19     A      3.     790817.1446.   790820.1300.       2443000.          923.           425.            546.
  20     A      4.     790425.1510.   790426. 956.       3010000.         2823.           885.           1401.
  21     A      4.     790425.1508.   790426. 956.       3010000.         2741.           854.           1350.
  22     A      4.     790430.1300.   790501.1024.       3010000.         3917.          1216.           1924.
  23     A      4.     790430.1258.   790501.1024.       3010000.         4063.          1300.           2057.
  24     A      4.     790817.1507.   790820.1322.       3007000.         1587.           732.           1156.
  25     A      4.     790817.1509.   790820.1322.       3007000.         1861.           858.           1356.
  26     AA     1.     781027.1118.   781028.1104.       1740000.         5081.          1618.           1480.
  27     AA     1.     781027.1117.   781028.1104.       1740000.         5614.          1775.           1623.
  28     AA     1.     781028. 940.   781029.1033.       1740000.         5027.          1639.           1499.
  29     AA     1.     781028. 939.   781029.1033.       1740000.         4537.          1468.           1343.
  30     AA     2.     790423.1330.   790424.1311.       1740000.         4135.          1435.           1312.
  31     AA     3.     790423.1332.   790424.1311.        920000.         5259.          1630.            788.
  32     B      1.     780920.1102.   780921. 929.       2660000.         3114.           997.           1394.
  33     B      1.     780920.1101.   780921. 902.       2660000.         3027.           966.           1350.
  34     B      1.     781017.1658.   781018.1054.       2260000.         3196.           967.           1148.
  35     B      1.     781017.1657.   781018.1054.       2260000.         2996.           913.           1085.
  36     B      1.     790403.1630.   790404. 956.       2340000.         2760.           857.           1054.
  37     B      1.     790403.1628.   790404. 956.       2340000.         2854.           880.           1082.
  38     B      2.     780920.1102.   780921. 929.       2830000.         3030.           963.           1432.
  39     B      2.     780920.1114.   780921. 902.       2830000.         3051.           965.           1435.
  40     B      2.     781027.1243.   781028.1123.       2590000.         3457.          1084.           1475.
  41     B      2.     781027.1244.   781028.1123.       2590000.         3271.          1033.           1406.
  42     B      2.     790404.1611.   790405.1034.       2890000.         3895.          1210.           1837.
  43     B      2.     790404.1609.   790405.1038.       2890000.         4073.          1237.           1879.
  44     B      3.     780920.1147.   780921. 929.       2540000.         2467.           791.           1056.
  45     B      3.     780920.1145.   780921. 902.       2540000.         2582.           825.           1102.
  46     B      3.     781017.1817.   781018.1126.       2700000.         2504.           753.           1069.
  47     B      3.     781017.1816.   781018.1126.       2700000.         2841.           861.           1222.
  48     B      3.     790403.1620.   790404. 956.       2660000.         2956.           892.           1247.
  49     B      3.     790403.1618.   790404. 956.       2660000.         2767.           841.           1176.
  50     B      4.     780920.1135.   780921. 929.       1130000.          163.            51.             30.
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			DATE.TIME OF					
COUNT	LINE	VENT#	COLLECTION	COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
51	B	4.	780920.1133.	780921. 902.	1130000.	166.	52.	31.
52	B	4.	781017.1752.	781018.1054.	1210000.	234.	70.	45.
53	B	4.	781017.1751.	781018.1054.	1210000.	168.	52.	33.
54	B	4.	790404.1618.	790405.1038.	1340000.	264.	80.	56.
55	B	4.	790404.1616.	790405.1038.	1340000.	234.	73.	52.
56	B	5.	780921.1137.	780922. 905.	1270000.	1480.	470.	314.
57	B	5.	780921.1136.	780922. 838.	1270000.	1696.	537.	359.
58	B	5.	781017.1712.	781018.1054.	1600000.	1911.	586.	493.
59	B	5.	781017.1711.	781018.1054.	1600000.	1913.	591.	497.
60	B	5.	790404.1556.	790405.1038.	1480000.	1307.	401.	312.
61	B	5.	790404.1551.	790405.1038.	1480000.	1241.	371.	288.
62	B	6.	780921.1147.	780922. 905.	802000.	447.	141.	59.
63	B	6.	780921.1146.	780922. 838.	802000.	451.	142.	60.
64	B	6.	790405.1513.	790406. 907.	1600000.	618.	183.	154.
65	B	6.	790405.1511.	790406. 907.	1600000.	596.	198.	167.
66	BB	1.	780921.1209.	780922. 905.	353000.	2861.	912.	169.
67	BB	1.	780921.1208.	780922. 838.	353000.	2784.	885.	164.
68	BB	1.	790402.1307.	790403. 827.	353000.	3765.	1173.	218.
69	BB	1.	790402.1305.	790403. 827.	353000.	4539.	1525.	283.
70	BB	2.	780921.1201.	780922. 838.	408000.	4315.	1332.	286.
71	BB	2.	780921.1203.	780922. 905.	408000.	5805.	1798.	385.
72	BB	2.	781027.1304.	781028.1123.	408000.	5861.	1874.	402.
73	BB	2.	781027.1306.	781028.1123.	408000.	6218.	1973.	423.
74	BB	2.	790402.1316.	790403. 827.	408000.	7888.	2409.	517.
75	BB	2.	790402.1314.	790403. 827.	408000.	8346.	2568.	551.
76	BB	4.	780922.1106.	780923. 837.	398000.	7298.	2268.	474.
77	BB	4.	780922.1108.	780923. 900.	398000.	6450.	2010.	420.
78	BB	4.	790402.1325.	790403. 827.	286000.	6278.	2045.	307.
79	BB	4.	790402.1323.	790403. 827.	286000.	8341.	2603.	391.
80	BB	5.	790402.1330.	790403. 827.	142000.	8522.	2598.	194.
81	BB	5.	790402.1328.	790403. 827.	142000.	8046.	2528.	189.
82	BB	8.	780922.1116.	780923. 837.	1150000.	4179.	1327.	802.
83	BB	8.	780922.1118.	780923. 900.	1150000.	4002.	1274.	770.
84	BB	8.	781025.1315.	781026. 935.	1150000.	4494.	1416.	856.
85	BB	8.	781025.1314.	781026. 935.	1150000.	5179.	1620.	979.
86	BB	8.	790402.1337.	790403. 848.	1040000.	4557.	1418.	775.
87	BB	8.	790402.1335.	790403. 848.	1040000.	4642.	1557.	851.
88	C	1.	780926.1039.	780927. 828.	1540000.	3152.	982.	795.
89	C	1.	780926.1038.	780927. 803.	1540000.	3889.	1208.	978.
90	C	1.	781025.1433.	781026. 958.	1910000.	5142.	1621.	1627.
91	C	1.	781025.1434.	781026. 958.	1910000.	5899.	1804.	1811.
92	C	1.	790404.1159.	790404.1705.	1390000.	6626.	1819.	1329.
93	C	1.	790404.1157.	790404.1705.	1390000.	5663.	1602.	1171.
94	C	3.	780926.1024.	780927. 828.	1360000.	7360.	2349.	1679.
95	C	3.	780926.1023.	780927. 803.	1360000.	7287.	2319.	1658.
96	C	3.	781024.1650.	781025. 905.	1360000.	4910.	1478.	1056.
97	C	3.	781024.1647.	781025. 905.	1360000.	5172.	1545.	1104.
98	C	3.	790403.1544.	790404. 956.	2920000.	3745.	1114.	1709.
99	C	3.	790404.1151.	790404.1705.	2920000.	4893.	1375.	2111.
100	C	3.	790404.1149.	790404.1705.	2920000.	4842.	1331.	2043.

COUNT	MINE	VENT#	DATE,TIME OF COLLECTION	DATE,TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
101	C	4.	780926.1107.	780927. 803.	1300000.	1640.	515.	352.
102	C	4.	780926.1108.	780927. 828.	1300000.	1230.	388.	265.
103	C	4.	781027.1417.	781028.1123.	913000.	2260.	721.	346.
104	C	4.	781027.1416.	781028.1123.	913000.	2248.	697.	334.
105	C	5.	780926.1141.	780927. 803.	2200000.	2513.	798.	922.
106	C	5.	780926.1142.	780927. 828.	2200000.	2380.	758.	876.
107	C	5.	781027.1429.	781028.1140.	2040000.	2840.	894.	958.
108	C	5.	781027.1430.	781028.1140.	2040000.	2736.	867.	930.
109	C	5.	790403.1519.	790404. 937.	2680000.	2884.	895.	1260.
110	C	5.	790403.1517.	790404. 937.	2680000.	2820.	856.	1205.
111	C	6.	780926.1057.	780927. 803.	1790000.	43.	13.	13.
112	C	6.	780926.1058.	780927. 828.	1790000.	32.	10.	9.
113	C	6.	790404.1208.	790404.1726.	1930000.	3084.	832.	844.
114	C	6.	790404.1206.	790404.1726.	1930000.	2241.	677.	687.
115	CC	1.	781017.1228.	781017.1943.	566000.	3992.	1139.	339.
116	CC	1.	781017.1229.	781017.1943.	566000.	3780.	1071.	318.
117	CC	1.	790419.1804.	790420. 839.	566000.	3506.	1058.	315.
118	CC	1.	790419.1806.	790420. 839.	566000.	2669.	811.	241.
119	CC	2.	781017.1215.	781017.1924.	2120000.	3619.	1017.	1133.
120	CC	2.	781017.1217.	781017.1924.	2120000.	3615.	1008.	1123.
121	CC	2.	781026.1448.	781027. 816.	2120000.	3657.	1136.	1265.
122	CC	2.	781026.1449.	781027. 816.	2120000.	3410.	1028.	1145.
123	CC	3.	781017.123[illegible].	781017.1943.	1674000.	2305.	648.	570.
124	CC	3.	781017.1234.	781017.1943.	1674000.	2769.	772.	679.
125	CC	3.	781026.1504.	781027. 816.	1674000.	2341.	720.	634.
126	CC	3.	781026.1503.	781027. 816.	1674000.	2277.	695.	612.
127	D	1.	790820.1931.	790821.1025.	4700000.	2219.	673.	1664.
128	D	1.	790820.1916.	790821.1025.	4700000.	2626.	798.	1972.
129	D	1.	790821.1151.	790822.1751.	4700000.	2345.	798.	1970.
130	D	1.	790821.1149.	790822.1751.	4700000.	2394.	814.	2012.
131	D	2.	790820.1933.	790821.1025.	3738000.	3019.	923.	1813.
132	D	2.	790820.1919.	790821.1025.	3738000.	2932.	888.	1744.
133	D	2.	790821.1153.	790822.1751.	3738000.	2731.	936.	1838.
134	D	2.	790821.1152.	790822.1751.	3738000.	2253.	763.	1500.
135	DD	1.	781017.1253.	781017.1924.	1130000.	2114.	587.	348.
136	DD	1.	781017.1254.	781017.1924.	1130000.	2143.	613.	364.
137	DD	1.	781027.1207.	781028.1104.	1130000.	1531.	488.	290.
138	DD	1.	781027.1206.	781028.1104.	1130000.	1451.	466.	277.
139	DD	2.	781017.1305.	781017.1924.	1220000.	3658.	1029.	660.
140	DD	2.	781017.1303.	781017.1924.	1220000.	3641.	1032.	662.
141	DD	2.	781027.1219.	781028.1104.	1220000.	2744.	861.	552.
142	DD	2.	781027.1218.	781028.1104.	1220000.	3358.	1085.	696.
143	F	1.	790407.1411.	790408. 931.	1480000.	17625.	5919.	4604.
144	F	1.	790407.1413.	790408. 931.	1480000.	17314.	5191.	4038.
145	F	1.	790409.1711.	790410.1221.	1480000.	19178.	5988.	4658.
146	F	1.	790409.1709.	790410.1221.	1480000.	20947.	6397.	4976.
147	F	2.	790407.1428.	790408. 931.	549000.	19261.	5876.	1695.
148	F	2.	790407.1426.	790408. 931.	549000.	14539.	4470.	1290.
149	F	2.	790409.1702.	790410.1221.	549000.	19911.	6132.	1769.
150	F	2.	790409.1700.	790410.1221.	549000.	22986.	6895.	1989.

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                               DATE.TIME  OF                 AIRFLOW      RADON ACT.     RADON CONC.   RADON EMISSION
 COUNT   MINE   VENT#   COLLECTION      COUNT               (L/MIN)     (CNTS/MIN)       (PCI/L)      RATE (CI/YR)
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  151     F       3.   790407.1436.  790408. 931.         1090000.         3991.           1253.            718.
  152     F       3.   790407.1434.  790408. 931.         1090000.         3747.           1168.            669.
  153     F       3.   790409.1657.  790410.1221.         1090000.         4613.           1550.            888.
  154     F       3.   790409.1655.  790410.1204.         1090000.         5130.           1566.            897.
  155     F       4.   790407.1445.  790408.1111.         1290000.          392.            133.             90.
  156     F       4.   790407.1443.  790408. 931.         1290000.          475.            145.             98.
  157     F       4.   790409.1650.  790410.1204.         1290000.          489.            154.            104.
  158     F       4.   790409.1648.  790410.1204.         1290000.          490.            153.            104.
  159     F       5.   790407.1452.  790408.1111.         1020000.         2325.            721.            387.
  160     F       5.   790407.1450.  790408.1111.         1020000.         2465.            745.            399.
  161     F       5.   790409.1645.  790410.1204.         1020000.         2905.            888.            476.
  162     F       5.   790409.1643.  790410.1204.         1020000.         2448.            754.            404.
  163     F       6.   790407.1458.  790408.1111.         2050000.         1710.            538.            580.
  164     F       6.   790407.1456.  790408.1111.         2050000.         2107.            649.            699.
  165     F       6.   790409.1639.  790410.1204.         2050000.         2871.            862.            928.
  166     F       6.   790409.1637.  790410.1204.         2050000.         2333.            784.            845.
  167     F       7.   790407.1504.  790408.1111.          313000.          102.             31.              5.
  168     F       7.   790407.1502.  790408.1111.          313000.           93.             29.              5.
  169     F       7.   790409.1634.  790410.1149.          313000.          377.            115.             19.
  170     F       7.   790409.1632.  790410.1149.          313000.          316.             99.             16.
  171     F       8.   790407.1528.  790408.1205.         1130000.        44786.          13563.           8055.
  172     F       8.   790407.1526.  790408.1205.         1130000.        43468.          14743.           8756.
  173     F       8.   790409.1002.  790409.1504.         1130000.        48892.          13823.           8210.
  174     F       8.   790409.1000.  790409.1504.         1130000.        49218.          13816.           8206.
  175     F       9.   790407.1534.  790408.1205.         1650000.        17098.           5274.           4574.
  176     F       9.   790407.1532.  790408.1205.         1650000.        14993.           4661.           4042.
  177     F       9.   790409.1624.  790410.1149.         1650000.        17763.           5475.           4748.
  178     F       9.   790409.1622.  790410.1149.         1650000.        18377.           5516.           4784.
  179     F      10.   790407.1544.  790408.1205.          436000.         8015.           2544.            583.
  180     F      10.   790407.1542.  790408.1205.          436000.         7439.           2344.            537.
  181     F      10.   790409.1628.  790410.1149.          436000.         8285.           2591.            594.
  182     F      10.   790409.1626.  790410.1149.          436000.         8891.           2719.            623.
  183     F      11.   790407.1552.  790408.1236.         1270000.         6538.           2219.           1481.
  184     F      11.   790407.1550.  790408.1205.         1270000.         7290.           2244.           1498.
  185     F      11.   790409.1615.  790410.1149.         1270000.         7248.           2438.           1628.
  186     F      11.   790409.1613.  790410.1131.         1270000.         7918.           2420.           1615.
  187     F      12.   790407.1605.  790408.1236.         1420000.         1610.            500.            373.
  188     F      12.   790407.1603.  790408.1236.         1420000.         1995.            604.            451.
  189     F      12.   790409.1558.  790410.1131.         1420000.         3103.            950.            709.
  190     F      12.   790409.1556.  790410.1131.         1420000.         3204.            989.            738.
  191     F      13.   790407.1612.  790408.1236.         1280000.        26030.           8204.           5519.
  192     F      13.   790407.1610.  790408.1236.         1280000.        26473.           8160.           5490.
  193     F      13.   790409.1548.  790410.1131.         1280000.        28978.           8716.           5864.
  194     F      13.   790409.1546.  790410.1131.         1280000.        25649.           8640.           5813.
  195     F      14.   790407.1621.  790408.1236.          779000.         1693.            521.            213.
  196     F      14.   790407.1619.  790408.1236.          779000.         1453.            461.            189.
  197     F      14.   790409.1607.  790410.1131.          779000.         2576.            812.            332.
  198     F      14.   790409.1605.  790410.1131.          779000.         2609.            816.            334.
  199     FF      1.   790516.1318.  790517. 651.         2360000.        13401.           4073.           5052.
  200     FF      1.   790516.1318.  790517. 651.         2360000.        14186.           4279.           5307.
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COUNT	MINE	VENT#	DATE.TIME OF COLLECTION	DATE.TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
201	FE	1.	790516.1318.	790517. 622.	2360000.	13327.	4050.	5024.
202	FE	1.	790516.1318.	790517. 622.	2360000.	14062.	4258.	5281.
203	FE	2.	790516.1400.	790517. 622.	424000.	567.	173.	39.
204	FE	2.	790516.1400.	790517. 622.	424000.	617.	184.	41.
205	FE	3.	790516.1415.	790517. 736.	149000.	386.	116.	9.
206	FE	3.	790516.1415.	790517. 622.	149000.	302.	93.	7.
207	FE	3.	790516.1415.	790517. 622.	149000.	373.	111.	9.
208	FE	3.	790516.1415.	790517. 736.	149000.	344.	107.	8.
209	FE	4.	790516.1440.	790517. 736.	380000.	1548.	468.	94.
210	FE	4.	790516.1440.	790517. 651.	380000.	1374.	415.	83.
211	FE	4.	790516.1440.	790517. 651.	380000.	1512.	451.	90.
212	FE	4.	790516.1440.	790517. 736.	380000.	1411.	428.	86.
213	FE	5.	790516.1522.	790517. 651.	601000.	12090.	3699.	1168.
214	FE	5.	790516.1522.	790517. 651.	601000.	12508.	3799.	1200.
215	F	1.	780928. 913.	780929.1439.	612000.	4996.	1686.	542.
216	F	1.	780928. 912.	780929.1138.	612000.	5050.	1666.	536.
217	F	1.	781027.1447.	781028.1140.	612000.	5995.	1854.	596.
218	F	1.	781027.1449.	781028.1140.	612000.	5453.	1737.	559.
219	F	1.	790404.1134.	790404.1705.	303000.	6771.	2048.	326.
220	F	1.	790404.1132.	790404.1705.	303000.	7809.	2151.	343.
221	F	2.	780927.1053.	780928. 736.	428000.	7723.	2386.	537.
222	F	2.	780927.1051.	780928. 704.	428000.	7599.	2339.	526.
223	F	2.	781025.1338.	781026. 958.	428000.	6880.	2151.	484.
224	F	2.	781025.1339.	781026. 959.	428000.	7762.	2445.	550.
225	F	2.	790404.1127.	790404.1645.	289000.	9978.	2827.	429.
226	F	2.	790404.1125.	790404.1645.	289000.	10237.	2879.	437.
227	F	3.	780928. 923.	780929.1439.	289000.	17343.	5802.	881.
228	F	3.	780928. 922.	780929.1138.	289000.	18968.	6203.	942.
229	F	3.	781024.1642.	781025. 836.	289000.	23548.	7014.	1065.
230	F	3.	781024.1641.	781025. 836.	289000.	23001.	6904.	1049.
231	F	3.	781029.1447.	781030.1033.	289000.	20409.	6354.	965.
232	F	3.	781029.1446.	781030.1033.	289000.	20670.	6484.	985.
233	F	3.	790404.1141.	790404.1705.	501000.	17094.	4739.	1248.
234	F	3.	790404.1139.	790404.1705.	501000.	22121.	5973.	1573.
235	F	4.	780928. 931.	780929.1439.	1320000.	5145.	1745.	1211.
236	F	4.	780928. 930.	780929.1138.	1320000.	5837.	1935.	1343.
237	F	4.	781024.1427.	781025. 836.	1190000.	7531.	2282.	1427.
238	F	4.	781024.1425.	781025. 836.	1190000.	7833.	2446.	1530.
239	F	4.	790403.1601.	790404. 937.	1210000.	8390.	2551.	1622.
240	F	4.	790403.1559.	790404. 937.	1210000.	9652.	2858.	1818.
241	F	5.	780925.1100.	780926. 907.	351000.	12608.	4055.	748.
242	F	5.	780925.1059.	780926. 844.	351000.	12525.	4018.	741.
243	F	5.	781024.1732.	781025. 931.	351000.	17892.	5333.	984.
244	F	5.	781024.1730.	781025. 931.	351000.	16799.	5160.	952.
245	F	5.	790403.1439.	790404. 915.	255000.	7890.	2399.	321.
246	F	5.	790403.1437.	790404. 915.	255000.	6474.	1984.	266.
247	F	6.	780925.1108.	780926. 907.	1620000.	3044.	949.	808.
248	F	6.	780925.1107.	780926. 844.	1620000.	3075.	956.	814.
249	F	6.	781024.1751.	781025. 905.	1620000.	3230.	972.	827.
250	F	6.	781024.1750.	781025. 905.	1620000.	3261.	989.	842.

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                              DATE.TIME  OF              AIRFLOW      RADON ACT.     RADON CONC.   RADON EMISSION
COUNT    MINE    VENT#    COLLECTION      COUNT           (L/MIN)     (CNTS/MIN)       (PCI/L)      RATE (CI/YR)
----------------------------------------------------------------------------------------------------------------
 251      F        6.   790403.1449.  790404. 915.      1300000.        3012.            942.            644.
 252      F        6.   790403.1447.  790404. 915.      1300000.        3212.            998.            682.
 253      F        7.   780927.1157.  780928. 736.       556000.        1615.            506.            148.
 254      F        7.   780927.1156.  780928. 704.       556000.        1636.            511.            149.
 255      F        7.   781024.1712.  781025. 905.       556000.        1782.            531.            155.
 256      F        7.   781024.1711.  781025. 905.       556000.        1848.            567.            166.
 257      F        7.   790404.1215.  790404.1726.       447000.        3303.            907.            213.
 258      F        7.   790404.1213.  790404.1726.       447000.        3310.            916.            215.
 259      F        8.   780927. 956.  780928. 736.      1860000.        2357.            744.            728.
 260      F        8.   780927. 955.  780928. 704.      1860000.        2480.            780.            763.
 261      F        8.   781026.1551.  781027. 750.      1860000.        3124.            931.            910.
 262      F        8.   781026.1548.  781027. 750.      1860000.        2802.            842.            823.
 263      F        8.   790405.1355.  790406. 849.      1710000.        2760.            860.            773.
 264      F        8.   790405.1353.  790406. 848.      1710000.        3105.            946.            850.
 265      F       10.   780927.1058.  780928. 704.       960000.        4208.           1333.            673.
 266      F       10.   780927.1059.  780928. 736.       960000.        3564.           1133.            572.
 267      F       10.   781024.1742.  781025. 931.       960000.        6442.           1961.            990.
 268      F       10.   781024.1743.  781025. 931.       960000.        5994.           1811.            914.
 269      F       10.   790403.1432.  790404. 915.       430000.        4649.           1388.            314.
 270      F       10.   790403.1430.  790404. 915.       430000.        4968.           1661.            375.
 271      F       12.   790404.1116.  790404.1645.      1250000.        8634.           2377.           1562.
 272      F       12.   790404.1114.  790404.1645.      1250000.        7861.           2181.           1433.
 273      F       13.   780928. 856.  780929.1439.      1620000.        1660.            549.            467.
 274      F       13.   780928. 855.  780929.1138.      1620000.        1607.            519.            442.
 275      F       13.   781024.1416.  781025. 836.      1620000.        2325.            716.            610.
 276      F       13.   781024.1416.  781025. 836.      1620000.        1844.            572.            487.
 277      F       13.   790405.1402.  790406. 848.      1850000.        2429.            739.            719.
 278      F       13.   790405.1400.  790406. 848.      1850000.        1988.            624.            606.
 279      F       14.   781025.1359.  781026. 935.       567000.        6615.           2026.            604.
 280      F       14.   781025.1357.  781026. 935.       567000.        6208.           1960.            584.
 281      F       14.   790403.1457.  790404. 937.       456000.        7258.           2425.            581.
 282      F       14.   790403.1455.  790404. 915.       456000.        8371.           2540.            609.
 283      F       15.   780927.1033.  780928. 736.      1360000.          22.              7.              5.
 284      F       15.   780927.1032.  780928. 704.      1360000.          21.              6.              5.
 285      F       15.   790404.1108.  790404.1645.      1170000.        1113.            301.            185.
 286      F       15.   790404.1106.  790404.1645.      1170000.        1332.            403.            248.
 287      FF       1.   790411.1452.  790412. 941.      1240000.        4590.           1440.            939.
 288      FF       1.   790411.1450.  790412. 941.      1240000.        4115.           1282.            835.
 289      FF       2.   790411.1458.  790412. 941.       420000.        3254.            990.            219.
 290      FF       2.   790411.1500.  790412. 959.       420000.        3016.           1010.            223.
 291      FF       3.   790411.1504.  790412. 959.       650000.       13344.           3989.           1363.
 292      FF       3.   790411.1506.  790412. 959.       650000.       13759.           4224.           1443.
 293      G        1.   781021.1156.  781021.1920.       275400.        5569.           1721.            249.
 294      G        1.   781021.1154.  781021.1920.       275400.        5041.           1451.            210.
 295      G        1.   790405.1437.  790406. 820.       232000.        4977.           1475.            180.
 296      G        1.   790405.1435.  790406. 820.       232000.        4127.           1369.            167.
 297      G        2.   781021.1124.  781021.1856.       850000.        1278.            363.            162.
 298      G        2.   781021.1125.  781021.1856.       850000.        1207.            345.            154.
 299      G        2.   790405.1427.  790406. 820.       800000.        1213.            367.            154.
 300      G        2.   790405.1425.  790406. 820.       800000.        1090.            332.            140.
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COUNT	MINE	VENT#	DATE.TIME OF COLLECTION	DATE.TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
301	G	3.	781021.1143.	781021.1856.	2259000.	3577.	998.	1185.
302	G	3.	781021.1144.	781021.1856.	2259000.	3620.	1040.	1235.
303	G	3.	790405.1420.	790406. 820.	2680000.	3101.	967.	1362.
304	G	3.	790405.1418.	790406. 820.	2680000.	3196.	989.	1394.
305	G	4.	781021.1119.	781021.1856.	932000.	2716.	760.	372.
306	G	4.	781021.1118.	781021.1856.	932000.	2517.	710.	348.
307	G	4.	790405.1432.	790406. 848.	1210000.	1499.	499.	318.
308	G	4.	790405.1430.	790406. 820.	1210000.	1995.	603.	383.
309	G	5.	781023.1147.	781023.2053.	1089000.	637.	180.	103.
310	G	5.	781023.1146.	781023.2053.	1089000.	683.	195.	111.
311	G	5.	790405.1409.	790406. 848.	991000.	667.	204.	106.
312	G	5.	790405.1407.	790406. 848.	991000.	667.	199.	104.
313	GG	1.	781018.1417.	781019. 844.	1230000.	698.	217.	140.
314	GG	1.	781018.1418.	781019. 844.	1230000.	649.	200.	129.
315	GG	1.	781018.1419.	781019. 844.	1230000.	736.	230.	149.
316	GG	1.	790410.1905.	790411.1115.	1230000.	250.	75.	48.
317	GG	1.	790410.1903.	790411.1115.	1230000.	322.	97.	63.
318	GG	1.	790411.1301.	790412. 921.	1230000.	285.	86.	56.
319	GG	1.	790411.1259.	790412. 921.	1230000.	207.	70.	45.
320	GG	2.	790411.1255.	790412.1255.	300000.	844.	267.	42.
321	GG	2.	790411.1253.	790412.1253.	300000.	782.	250.	39.
322	GG	2.	790420.1725.	790421.1355.	300000.	1021.	317.	50.
323	GG	2.	790420.1723.	790421.1355.	300000.	1239.	375.	59.
324	GG	3.	790411.1250.	790412. 921.	206000.	2598.	826.	89.
325	GG	3.	790411.1248.	790412. 921.	206000.	2656.	838.	91.
326	GG	3.	790420.1745.	790421.1355.	206000.	2475.	779.	84.
327	GG	3.	790420.1744.	790421.1355.	206000.	2539.	781.	85.
328	H	1.	790406.1357.	790407. 847.	1410000.	2448.	768.	569.
329	H	1.	790406.1355.	790407. 847.	1410000.	2621.	817.	605.
330	H	1.	790408.1428.	790409. 719.	1410000.	2956.	914.	677.
331	H	1.	790408.1426.	790409. 719.	1410000.	2684.	824.	610.
332	H	2.	790406.1407.	790407.1131.	575000.	1994.	680.	206.
333	H	2.	790406.1405.	790407. 847.	575000.	2401.	730.	221.
334	H	2.	790408.1422.	790409. 719.	575000.	2341.	703.	212.
335	H	2.	790408.1420.	790409. 719.	575000.	2077.	628.	190.
336	H	3.	790406.1418.	790407.1131.	1280000.	1970.	615.	414.
337	H	3.	790406.1416.	790407.1131.	1280000.	2054.	625.	420.
338	H	3.	790408.1415.	790409. 719.	1280000.	2231.	658.	443.
339	H	3.	790408.1413.	790409. 719.	1280000.	1691.	558.	376.
340	H	4.	790406.1543.	790407.1131.	399000.	12172.	3819.	801.
341	H	4.	790406.1541.	790407.1131.	399000.	13895.	4264.	894.
342	H	4.	790408.1512.	790409. 806.	399000.	15418.	4540.	952.
343	H	4.	790408.1510.	790409. 806.	399000.	12562.	4143.	869.
344	H	5.	790406.1553.	790407.1131.	1240000.	25042.	7673.	5001.
345	H	5.	790406.1551.	790407.1131.	1240000.	22582.	7131.	4647.
346	H	5.	790408.1522.	790409. 806.	1240000.	27130.	8132.	5300.
347	H	5.	790408.1520.	790409. 806.	1240000.	23639.	7141.	4654.
348	H	6.	790406.1603.	790407.1151.	1270000.	5036.	1516.	1012.
349	H	6.	790406.1601.	790407.1151.	1270000.	3920.	1321.	882.
350	H	6.	790408.1530.	790409. 806.	1270000.	4069.	1255.	838.

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                            DATE.TIME  OF                 AIRFLOW      RADON ACT.     RADON CONC.    RADON EMISSION
COUNT   MINE   VENT#   COLLECTION      COUNT              (L/MIN)      (CNTS/MIN)       (PCI/L)       RATE (CI/YR)
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 351     H       6.    790408.1528.  790409. 806.        1270000.         4938.          1513.            1010.
 352     H       7.    790406.1622.  790407.1151.        1530000.         2416.           739.             595.
 353     H       7.    790406.1620.  790407.1151.        1530000.         2610.           805.             647.
 354     H       7.    790408.1459.  790409. 748.        1530000.         2211.           683.             549.
 355     H       7.    790408.1501.  790409. 748.        1530000.         2271.           681.             548.
 356     H       8.    790406.1631.  790407.1151.        1370000.         4530.          1427.            1027.
 357     H       8.    790406.1629.  790407.1151.        1370000.         4141.          1295.             933.
 358     H       8.    790408.1435.  790409. 748.        1370000.         6040.          1996.            1437.
 359     H       8.    790408.1433.  790409. 719.        1370000.         7137.          2140.            1541.
 360     H       9.    790406.1641.  790407.1208.         153000.         5334.          1793.             144.
 361     H       9.    790406.1639.  790407.1151.         153000.         5894.          1800.             145.
 362     H       9.    790408.1442.  790409. 748.         153000.         7187.          2177.             175.
 363     H       9.    790408.1440.  790409. 748.         153000.         7421.          2189.             176.
 364     H      10.    790406.1648.  790407.1208.         960000.        31974.          9849.            4969.
 365     H      10.    790406.1646.  790407.1208.         960000.        33012.          9903.            4997.
 366     H      10.    790408.1448.  790409. 748.         960000.        36170.         11111.            5606.
 367     H      10.    790408.1446.  790409. 748.         960000.        37513.         11270.            5687.
 368     HH      1.    790411.1401.  790412. 941.        2260000.         1078.           324.             385.
 369     HH      1.    790411.1359.  790412. 941.        2260000.          924.           311.             370.
 370     HH      1.    790420.1550.  790421.1332.        2260000.          802.           255.             303.
 371     HH      1.    790420.1552.  790421.1332.        2260000.          644.           206.             245.
 372     HH      2.    790411.1405.  790412. 941.        2450000.         1955.           603.             777.
 373     HH      2.    790411.1407.  790412. 941.        2450000.         1993.           610.             786.
 374     HH      2.    790420.1623.  790421.1332.        2450000.         1484.           460.             592.
 375     HH      2.    790420.1625.  790421.1355.        2450000.         1623.           554.             713.
 376     T       1.    790827.1251.  790827.1831.        2010000.         1033.           292.             309.
 377     T       1.    790827.1253.  790827.1831.        2010000.         1214.           344.             363.
 378     T       1.    790828.1108.  790829. 934.        2010000.         1086.           349.             369.
 379     T       1.    790828.1109.  790829. 934.        2010000.         1032.           330.             349.
 380     T       2.    790827.1355.  790827.1856.        2520000.          809.           227.             301.
 381     T       2.    790827.1353.  790827.1856.        2520000.          734.           200.             265.
 382     T       2.    790828.1542.  790829.1019.        2520000.          888.           276.             366.
 383     T       2.    790828.1543.  790829.1019.        2520000.          866.           272.             361.
 384     T       3.    790827.1404.  790828. 836.         118000.          764.           236.              15.
 385     T       3.    790827.1410.  790828. 836.         118000.          675.           213.              13.
 386     T       3.    790828.1134.  790829. 903.         118000.          776.           248.              15.
 387     T       3.    790828.1135.  790829. 903.         118000.          749.           243.              15.
 388     T       4.    790827.1418.  790828. 836.        2390000.         1010.           317.             398.
 389     T       4.    790827.1420.  790828. 836.        2390000.          972.           303.             380.
 390     T       4.    790828.1126.  790829. 903.        2390000.          868.           276.             347.
 391     T       4.    790828.1127.  790829. 903.        2390000.          835.           270.             339.
 392     T       5.    790827.1433.  790828. 901.         283000.          538.           166.              25.
 393     T       5.    790827.1435.  790828. 836.         283000.          484.           150.              22.
 394     T       5.    790828.1120.  790829. 903.         283000.          441.           142.              21.
 395     T       5.    790828.1121.  790829. 903.         283000.          366.           117.              17.
 396     T       6.    790827.1443.  790828. 836.         665000.          943.           292.             102.
 397     T       6.    790827.1444.  790828. 901.         665000.         1012.           315.             110.
 398     T       6.    790828.1535.  790829.1019.         665000.          663.           200.              70.
 399     T       7.    790827.1453.  790828.1115.          97000.          132.            42.               2.
 400     T       7.    790828.1454.  790829.1001.          97000.          206.            65.               3.
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COUNT	MINE	VENT#	DATE,TIME OF COLLECTION	DATE,TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
401	T	7.	790828.1456.	790829. 956.	97000.	147.	46.	2.
402	T	8.	790827.1518.	790828.1115.	93000.	603.	184.	9.
403	T	8.	790827.1519.	790828.1136.	93000.	533.	168.	8.
404	T	8.	790828.1517.	790829. 903.	93000.	599.	184.	9.
405	T	8.	790828.1518.	790829. 956.	93000.	588.	186.	9.
406	T	9.	790827.1515.	790828.1115.	963000.	343.	109.	55.
407	T	9.	790827.1516.	790828.1136.	963000.	497.	158.	80.
408	T	9.	790828.1219.	790829. 934.	963000.	496.	159.	81.
409	T	9.	790828.1220.	790829. 934.	963000.	465.	148.	75.
410	T	10.	790628.1510.	790829. 956.	963000.	755.	228.	115.
411	T	11.	790827.1558.	790828.1115.	2209000.	1184.	371.	431.
412	T	11.	790827.1559.	790828.1115.	2209000.	1174.	366.	424.
413	T	11.	790828.1037.	790829. 934.	2209000.	719.	224.	260.
414	T	11.	790828.1038.	790829. 934.	2209000.	487.	159.	184.
415	TI	1.	790518. 924.	790518.1426.	1620000.	922.	259.	220.
416	TI	1.	790518.1015.	790518.1451.	1620000.	691.	191.	163.
417	TI	1.	790518.1015.	790518.1451.	1620000.	683.	188.	160.
418	TI	1.	790518. 924.	790518.1426.	1620000.	741.	203.	173.
419	TI	2.	790518.1023.	790518.1451.	2660000.	778.	213.	297.
420	TI	2.	790518. 915.	790519.1426.	2660000.	841.	234.	327.
421	TI	2.	790518.1023.	790518.1451.	2660000.	515.	228.	318.
422	TI	2.	790518. 915.	790518.1426.	2660000.	878.	243.	340.
423	J	1.	781028.1003.	781029.1014.	454000.	746.	240.	57.
424	J	1.	781028.1002.	781029.1014.	454000.	891.	289.	69.
425	J	1.	781029.1250.	781030.1033.	454000.	1182.	368.	88.
426	J	1.	781029.1249.	781030.1033.	454000.	1090.	342.	82.
427	J	1.	790402.1059.	790402.1614.	515000.	1033.	290.	79.
428	J	1.	790402.1101.	790402.1614.	515000.	816.	240.	65.
429	J	2.	780924.1007.	780925. 858.	406000.	23991.	7532.	1607.
430	J	2.	780924.1006.	780925. 838.	406000.	24260.	7598.	1621.
431	J	2.	781028. 955.	781029.1033.	406000.	24651.	7844.	1674.
432	J	2.	781028. 956.	781029.1033.	406000.	23968.	7856.	1677.
433	J	2.	790402.1110.	790402.1614.	388000.	31342.	8603.	1754.
434	J	2.	790402.1108.	790402.1614.	388000.	29689.	8398.	1713.
435	J	3.	780924.1028.	780925. 858.	304000.	23947.	7668.	1225.
436	J	3.	780924.1027.	780925. 838.	304000.	23238.	7423.	1186.
437	J	3.	781026.1636.	781027. 750.	304000.	11409.	3381.	540.
438	J	3.	781026.1637.	741027. 750.	304000.	11639.	3554.	568.
439	J	4.	780925.1043.	780926. 907.	393000.	17961.	5619.	1161.
440	J	4.	780925.1042.	780926. 844.	393000.	20713.	6462.	1335.
441	J	4.	781026.1650.	781027. 816.	393000.	21462.	6371.	1316.
442	J	4.	781026.1649.	781027. 816.	393000.	21171.	6333.	1308.
443	J	4.	790402.1030.	790402.1538.	352000.	22176.	6090.	1127.
444	J	4.	790402.1028.	790402.1538.	352000.	18950.	5363.	992.
445	J	7.	780923.1118.	80924. 845.	513000.	26637.	8274.	2231.
446	J	7.	780923.1117.	0924. 821.	513000.	29274.	9067.	2445.
447	J	7.	781026.1624.	781027. 750.	513000.	18437.	5556.	1498.
448	J	7.	781026.1623.	781027. 750.	513000.	19109.	5802.	1564.
449	J	7.	790402.1119.	790402.1641.	430000.	19941.	5562.	1257.
450	J	7.	790402.1117.	790402.1641.	430000.	20332.	6146.	1389.

COUNT	MINE	VENT#	DATE.TIME OF COLLECTION	DATE.TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
451	J	8.	780924.1100.	780925. 858.	429000.	7752.	2459.	553.
452	J	8.	780924.1059.	780925. 838.	429000.	8271.	2612.	589.
453	J	8.	781029.1324.	781030.1012.	429000.	26100.	8068.	1819.
454	J	8.	781029.1322.	781030.1012.	429000.	26661.	8306.	1873.
455	J	8.	790402.1021.	790402.1538.	441000.	23078.	6777.	1571.
456	J	8.	790402.1019.	790402.1538.	441000.	27377.	7700.	1785.
457	J	9.	780924.1046.	780925. 858.	889000.	3826.	1231.	575.
458	J	9.	780924.1045.	780925. 838.	889000.	3903.	1253.	586.
459	J	9.	781028.1014.	781029.1014.	889000.	4072.	1289.	603.
460	J	9.	781028.1017.	781029.1014.	889000.	3798.	1211.	566.
461	J	9.	790402.1055.	790402.1614.	873000.	5001.	1376.	631.
462	J	9.	790402.1048.	790402.1614.	873000.	5287.	1466.	673.
463	J	10.	780925.1037.	780926. 907.	811000.	1955.	626.	267.
464	J	10.	780925.1036.	780926. 844.	811000.	2132.	681.	290.
465	J	10.	781029.1314.	781030.1012.	811000.	2880.	905.	386.
466	J	10.	781029.1315.	781030.1012.	811000.	2636.	834.	356.
467	J	10.	790402.1019.	790402.1538.	725000.	3649.	1005.	383.
468	J	10.	790402.1008.	790402.1538.	725000.	3514.	975.	372.
469	J	11.	780924.1040.	780925. 858.	628000.	839.	262.	87.
470	J	11.	780924.1039.	780925. 838.	628000.	931.	290.	96.
471	J	11.	781028.1012.	781029.1014.	628000.	920.	291.	96.
472	J	11.	781029.1011.	781029.1014.	628000.	780.	255.	84.
473	J	11.	781029.1302.	781030.1012.	628000.	1102.	342.	113.
474	J	11.	781029.1301.	781030.1012.	628000.	1149.	367.	121.
475	J	11.	790402.1040.	790402.1614.	1020000.	927.	260.	140.
476	J	11.	790402.1038.	790402.1614.	1020000.	968.	293.	157.
477	J	12.	780925.1027.	780926. 907.	778000.	787.	250.	102.
478	J	12.	780925.1026.	780926. 844.	778000.	967.	307.	125.
479	J	12.	790402. 959.	790402.1538.	1770000.	2630.	739.	687.
480	J	12.	790402. 957.	790402.1538.	1770000.	2671.	809.	753.
481	K	1.	781021.1221.	781021.1920.	509000.	8073.	2299.	615.
482	K	1.	781021.1223.	781021.1920.	509000.	7748.	2190.	586.
483	K	1.	790404.1404.	790405.1017.	555000.	7486.	2260.	659.
484	K	1.	790404.1402.	790405.1017.	555000.	6565.	2220.	648.
485	K	2.	781021.1240.	781021.1955.	2140000.	9621.	2746.	3088.
486	K	2.	781021.1239.	781021.1955.	2140000.	9865.	2795.	3143.
487	K	2.	790404.1416.	790405.1017.	2210000.	10439.	3305.	3839.
488	K	2.	790404.1414.	790405.1017.	2210000.	11363.	3572.	4149.
489	K	3.	781021.1230.	781021.1920.	832000.	1204.	345.	151.
490	K	3.	781021.1232.	781021.1920.	832000.	1306.	363.	159.
491	K	3.	790404.1409.	790405.1017.	1089000.	1104.	340.	194.
492	K	3.	790404.1408.	790405.1017.	1089000.	1176.	364.	209.
493	K	4.	781021.1249.	781021.1955.	2940000.	6284.	1805.	2789.
494	K	4.	781021.1250.	781021.1955.	2940000.	6357.	1772.	2738.
495	K	4.	790404.1426.	790405.1038.	2720000.	4474.	1512.	2162.
496	K	4.	790404.1424.	790405.1017.	2720000.	4940.	1516.	2168.
497	I	1.	781020.1318.	781021. 816.	485000.	692.	211.	54.
498	I	1.	781020.1317.	781021. 816.	485000.	1019.	313.	80.
499	I	1.	781023.1328.	781023.2053.	485000.	984.	279.	71.
500	I	1.	781023.1327.	781023.2053.	485000.	1149.	328.	84.

COUNT	MINE	VENT#	DATE.TIME OF COLLECTION	DATE.TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
501	I	1.	790410.1622.	790411.1037.	485000.	1527.	509.	130.
502	L	1.	790410.1624.	790411.1037.	485000.	1879.	559.	142.
503	I	2.	781020.1436.	781021. 904.	75800.	3181.	966.	38.
504	I	2.	781020.1435.	781021. 904.	75800.	3102.	971.	39.
505	I	2.	781023.1423.	781023.2155.	75800.	3913.	1094.	44.
506	I	2.	781023.1422.	781023.2155.	75800.	3877.	1117.	45.
507	L	2.	790410.1646.	790411.1037.	75800.	3010.	917.	37.
508	L	2.	790410.1648.	790411.1037.	75800.	3062.	925.	37.
509	L	3.	781020.1422.	781021. 838.	850000.	2382.	733.	328.
510	L	3.	781020.1421.	781021. 838.	850000.	2589.	803.	359.
511	I	3.	781023.1411.	781023.2155.	850000.	2208.	628.	280.
512	L	3.	781023.1412.	781023.2155.	850000.	2279.	653.	292.
513	L	3.	790410.1720.	790411.1037.	850000.	1237.	381.	170.
514	I	3.	790410.1722.	790411.1037.	850000.	1262.	391.	175.
515	L	4.	781020.1415.	781021. 838.	425000.	5658.	1717.	384.
516	I	4.	781020.1413.	781021. 838.	425000.	5487.	1678.	375.
517	I	4.	781023.1405.	781023.2116.	425000.	5480.	1528.	341.
518	I	4.	781023.1404.	781023.2116.	425000.	4979.	1431.	320.
519	I	4.	790410.1725.	790411.1037.	425000.	3138.	944.	211.
520	I	4.	790410.1727.	790411.1056.	425000.	2608.	864.	193.
521	L	5.	790410.1733.	790411.1056.	247000.	9615.	2842.	369.
522	I	5.	790410.1735.	790411.1056.	247000.	8090.	2455.	319.
523	I	6.	790410.1815.	790411.1056.	309000.	4487.	1345.	218.
524	I	6.	790410.1817.	790411.1056.	309000.	3929.	1204.	196.
525	L	7.	781020.1401.	781021. 838.	431000.	3474.	1056.	239.
526	I	7.	781020.1400.	781021. 838.	431000.	3521.	1103.	250.
527	I	7.	781023.1355.	781023.2116.	431000.	3213.	911.	206.
528	L	7.	781023.1354.	781023.2116.	431000.	2984.	852.	193.
529	I	7.	790410.1810.	790411.1056.	431000.	3452.	1066.	242.
530	I	7.	790410.1812.	790411.1056.	431000.	3649.	1094.	248.
531	L	8.	781020.1346.	781021. 816.	444000.	2020.	614.	143.
532	I	8.	781020.1345.	781021. 816.	444000.	1640.	513.	120.
533	I	8.	781023.1347.	781023.2116.	444000.	2449.	685.	160.
534	I	8.	781023.1346.	781023.2116.	444000.	2262.	637.	149.
535	L	8.	790410.1804.	790411.1115.	444000.	1496.	494.	115.
536	I	8.	790410.1806.	790411.1115.	444000.	1976.	583.	136.
537	I	9.	781020.1333.	781021. 816.	685000.	1759.	543.	196.
538	L	9.	781020.1332.	781021. 816.	685000.	1422.	443.	159.
539	I	9.	781023.1337.	781023.2053.	685000.	1634.	456.	164.
540	L	9.	781023.1336.	781023.2053.	685000.	1817.	523.	188.
541	D	2.	780922.1134.	780923. 900.	707000.	15610.	4919.	1828.
542	D	2.	780922.1135.	780923. 837.	707000.	15108.	4749.	1765.
543	D	2.	781025.1448.	781026. 935.	707000.	18319.	5577.	2072.
544	D	2.	781025.1447.	781026. 935.	707000.	19412.	5955.	2213.
545	D	2.	790403.1150.	790403.1732.	720000.	18877.	5719.	2164.
546	D	2.	790403.1145.	790403.1704.	720000.	10543.	5097.	1929.
547	D	3.	790403.1211.	790403.1732.	217000.	13807.	3884.	443.
548	D	3.	790403.1209.	790403.1732.	217000.	14450.	3976.	453.
549	D	5.	781025.1504.	781026. 914.	408000.	37392.	11671.	2503.
550	D	5.	781025.1505.	781026. 914.	408000.	38798.	11755.	2521.

COUNT	MINE	VENT#	DATE,TIME OF COLLECTION	DATE,TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
551	D	6.	780923.1103.	780924. 845.	351000.	52894.	16462.	3037.
552	D	6.	780923.1102.	780924. 821.	351000.	54862.	17018.	3140.
553	D	6.	781025.1500.	781026. 914.	351000.	69481.	21384.	3945.
554	D	6.	781025.1458.	781026. 914.	351000.	68620.	21220.	3915.
555	D	6.	790403.1141.	790403.1704.	280000.	68913.	19535.	2875.
556	D	6.	790403.1139.	790403.1704.	280000.	64399.	18125.	2667.
557	D	7.	780923.1037.	780924. 845.	572000.	20360.	6502.	1955.
558	D	7.	780923.1036.	780924. 821.	572000.	22584.	7191.	2162.
559	D	7.	790403.1132.	790403.1704.	704000.	26615.	7331.	2713.
560	D	7.	790403.1130.	790403.1704.	704000.	22142.	6147.	2274.
561	D	8.	780922.1147.	780923. 900.	1030000.	16920.	5406.	2926.
562	D	8.	780922.1145.	780923. 837.	1030000.	21699.	6914.	3743.
563	D	8.	781029.1411.	781030.1103.	1030000.	24296.	7628.	4129.
564	D	8.	781029.1410.	781030.1103.	1030000.	22688.	7177.	3885.
565	D	8.	790403.1220.	790403.1732.	1030000.	22038.	6055.	3278.
566	D	8.	790403.1218.	790403.1732.	1030000.	20142.	5703.	3087.
567	D	9.	780923.1056.	780924. 845.	162000.	872.	276.	23.
568	D	9.	780923.1055.	780924. 821.	162000.	829.	261.	22.
569	D	9.	781025.1453.	781026. 914.	162000.	2176.	660.	56.
570	D	9.	781025.1452.	781026. 914.	162000.	2456.	751.	64.
571	D	9.	790403.1121.	790403.1704.	229000.	6206.	1880.	226.
572	D	9.	790403.1122.	790403.1704.	229000.	5946.	1609.	194.
573	D	10.	780923.1044.	780924. 845.	811000.	4674.	1503.	641.
574	D	10.	780923.1043.	780924. 821.	811000.	4746.	1521.	648.
575	D	10.	790403.1158.	790403.1732.	585000.	14745.	4093.	1259.
576	D	10.	790403.1156.	790403.1732.	585000.	15179.	4104.	1262.
577	D	11.	780922.1155.	780923. 900.	1200000.	692.	214.	135.
578	D	11.	780922.1154.	780923. 837.	1200000.	653.	202.	127.
579	D	11.	781029.1417.	781030.1033.	1200000.	1065.	328.	207.
580	D	11.	781029.1418.	781030.1033.	1200000.	979.	310.	196.
581	D	11.	790403.1225.	790403.1754.	860000.	723.	195.	88.
582	D	11.	790403.1224.	790403.1754.	860000.	763.	231.	104.
583	T	1.	790822.1855.	790823.1545.	1682000.	828.	261.	231.
584	T	1.	790822.1852.	790823.1545.	1682000.	776.	246.	218.
585	T	1.	790823.1109.	790824.1120.	1682000.	855.	280.	248.
586	T	1.	790823.1107.	790824.1120.	1682000.	855.	277.	245.
587	T	2.	790823.1403.	790824.1142.	3030000.	830.	263.	419.
588	T	2.	790823.1405.	790824.1120.	3030000.	742.	236.	376.
589	T	2.	790824.1042.	790824.1628.	3030000.	724.	207.	329.
590	T	2.	790824.1044.	790824.1628.	3030000.	857.	243.	386.
591	T	3.	790823.1354.	790824.1120.	2670000.	1642.	524.	735.
592	T	3.	790823.1356.	790824.1142.	2670000.	1612.	521.	731.
593	T	3.	790824.1058.	790824.1628.	2670000.	1574.	445.	624.
594	T	3.	790824.1059.	790824.1628.	2670000.	1876.	528.	741.
595	T	4.	790822.2013.	790823.1605.	3398000.	1097.	349.	624.
596	T	4.	790822.2014.	790823.1545.	3398000.	1258.	400.	714.
597	T	4.	790823.1125.	790824.1120.	3398000.	1495.	482.	861.
598	T	4.	790823.1127.	790824.1142.	3398000.	1489.	469.	837.
599	T	5.	790822.2029.	790823.1605.	563000.	3175.	991.	293.
600	T	5.	790822.2030.	790823.1545.	563000.	2002.	607.	180.

COUNT	MINE	VENT#	DATE.TIME OF COLLECTION	DATE.TIME OF COUNT	AIRFLOW (L/MIN)	RADON ACT. (CNTS/MIN)	RADON CONC. (PCI/L)	RADON EMISSION RATE (CI/YR)
601	T	5.	790823.1414.	790824.1120.	563000.	2985.	918.	272.
602	T	5.	790823.1416.	790824.1142.	563000.	2923.	928.	275.
603	U	1.	790425.1021.	790426. 937.	2500000.	552.	191.	251.
604	U	1.	790425.1023.	790426. 937.	2500000.	614.	190.	249.
605	U	2.	790425.1039.	790426. 937.	860000.	1171.	371.	168.
606	U	3.	790425.1206.	790426. 937.	2330000.	1262.	401.	491.
607	U	3.	790425.1208.	790426. 937.	2330000.	1159.	371.	454.
608	V	1.	790406.1325.	790407. 847.	2400000.	1141.	342.	432.
609	V	1.	790406.1323.	790407. 847.	2400000.	818.	275.	347.
610	V	1.	790409. 930.	790409.1504.	2400000.	1617.	437.	551.
611	V	1.	790409. 924.	790409.1504.	2400000.	1288.	390.	492.
612	V	2.	790406.1337.	790407. 847.	2950000.	1031.	315.	488.
613	V	2.	790406.1335.	790407. 847.	2950000.	1044.	321.	498.
614	V	2.	790409. 934.	790409.1504.	2950000.	1353.	373.	578.
615	V	2.	790409. 932.	790409.1504.	2950000.	1507.	418.	648.
616	Y	1.	790424.1526.	790424.2049.	2820000.	7104.	2147.	3182.
617	Y	1.	790424.1528.	790424.2049.	2820000.	8039.	2169.	3215.
618	Y	2.	790424.1128.	790424.2011.	5321000.	3976.	1147.	3209.
619	Y	2.	790424.1130.	790424.2011.	5321000.	3565.	1036.	2898.
620	Y	3.	790424.1150.	790424.2029.	3300000.	3787.	1048.	1817.
621	Y	3.	790424.1155.	790424.2029.	3300000.	3627.	1030.	1786.
622	Y	4.	790424.1341.	790424.2029.	3180000.	8076.	2246.	3754.
623	Y	4.	790424.1343.	790424.2029.	3190000.	7247.	2061.	3444.
624	Y	5.	790424. 943.	790424.2011.	2520000.	4084.	1176.	1558.
625	Y	5.	790424. 945.	790424.2011.	2520000.	3686.	1054.	1395.
626	Y	5.	790425.1840.	790426.1018.	2520000.	4256.	1265.	1676.
627	Y	5.	790425.1842.	790426.1018.	2520000.	3788.	1151.	1525.
628	Y	6.	790424.1425.	790424.2029.	2850000.	4844.	1380.	2068.
629	Y	6.	790424.1427.	790424.2029.	2850000.	5112.	1413.	2117.
630	Y	6.	790425.1727.	790426.1018.	2850000.	4563.	1343.	2012.
631	Y	6.	790425.1729.	790426.1019.	2850000.	4262.	1288.	1929.
632	Y	7.	790424.1133.	790424.2011.	4124000.	4170.	1176.	2549.
633	Y	7.	790424.1135.	790424.2029.	4124000.	3103.	963.	2087.
634	Z	1.	781017.1149.	781017.1858.	2128000.	5220.	1467.	1640.
635	Z	1.	781026.1352.	781027. 840.	2128000.	4693.	1461.	1635.
636	Z	1.	790419.1539.	790420. 839.	2128000.	6101.	2013.	2251.
637	Z	1.	790419.1541.	790420. 839.	2128000.	7328.	2159.	2415.
638	Z	2.	781017.1156.	781017.1858.	1877000.	3085.	879.	867.
639	Z	2.	781017.1158.	781017.1858.	1877000.	3016.	853.	841.
640	Z	2.	781026.1403.	781027. 840.	1877000.	2188.	685.	676.
641	Z	2.	781026.1405.	781027. 840.	1877000.	2003.	609.	601.
642	Z	3.	781017.1205.	781017.1858.	991000.	1607.	461.	240.
643	Z	3.	781017.1205.	781017.1858.	991000.	1809.	503.	262.
644	Z	3.	781026.1417.	781027. 840.	991000.	1378.	421.	220.
645	Z	3.	781026.1415.	781027. 840.	991000.	1642.	498.	260.

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