CHAPTER 10
IONIZING RADIATION

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Chapter 10
IONIZING RADIATION

I. Introduction

This chapter includes sampling procedures for evaluating four types of ionizing radiation hazards**:** ***alpha, beta, gamma, and x-ray*****.** Ionizing radiation can cause cancer. At high doses, ionizing radiation causes radiation sickness. Ionizing radiation can be emitted by the mined ore, the surrounding rock, or nuclear gauges such as those that monitor the flow of materials. Miners can be exposed to hazardous levels of ionizing radiation at mines other than those producing radioactive minerals.

II. Definitions

Alpha Counter/Scaler - an instrument that counts alpha decay events when used with a scintillation detector.

Alpha Radiation - a **particle** that has a positive (+2) charge and is emitted from the nucleus of an atom. An alpha particle consists of two protons and two neutrons. When inhaled, dust containing alpha producing particles can cause lung cancer. While alpha particles travel at a high energy rate, they are so large that a sheet of paper or a few centimeters of air can block their path. Alpha particles are emitted by radon, uranium, and thoron. Examples of alpha emitters are uranium-238, radium-226, and radon-222.

Beta Radiation - a **particle** that has a negative (-1) charge and is emitted from the electron shell of an atom. A beta particle consists of one electron. Beta radiation has more penetrating capability than alpha radiation because the particle is much smaller. Even so, a light-weight barrier material, such as cardboard or sheet metal, can block beta radiation.

Gamma Radiation - short wavelength electromagnetic radiation emitted from radioactive elements such as uranium. Lead or concrete can block this type of radiation.

Geiger-Mueller counter - small hand-held meter designed to measure x-ray and gamma radiation.

Half-life - the time required for a radioactive substance to lose 50 % of its activity by decay. Each radionuclide has a characteristic half-life.

Ionizing Radiation - a form of energy capable of changing a stable, electrically-neutral atom into an unstable electrically-charged particle (ion). Radiation from uranium, radon, and other radioactive sources is ionizing.

Isotope - a form of an element that differs from other forms of the same element in the number of neutrons in each atom's nucleus. Isotopes of the same element may have different levels of stability and potential radioactivity.

Kusnetz method - a method for determining exposure to alpha radiation emitted from radon and thoron daughters/progeny. It was developed in the 1950's by H. L. Kusnetz.

Radioactive decay - the natural process of a radioactive material shedding mass from its nucleus. After each decay event, another element or isotope of lesser mass is formed. The decay process trends toward more stable elements with elemental lead (Pb 207) the most stable.

Radon - the radioactive gas produced by the radioactive decay of the element radium.

Radon Daughters/Radon Progeny - unstable, short-lived decay products of radon gas which emit alpha particles during the decay process. (Terms are used interchangeably.)

REM - abbreviation of **Roentgen Equivalent Man** - a unit for measuring the absorbed dose by humans (and biological effects) of ionizing radiation. Personal exposure limits for gamma and X-Ray radiation are expressed in REMs.

Roentgen (R) - a unit for measuring X-rays or gamma rays. For radiation protection, one R equals the dose measurement of one REM.

Scintillation detector - type of detector used to determine alpha emissions from filter samples. Operates as photons are released from a zinc sulfide phosphor and amplified with a photo-multiplier tube. Works in train with an alpha scaler/counter.

Thoron - a gas formed from the radioactive decay of thorium (Th), an element. Thoron is similar to radon as a health hazard in that respirable thoron daughters/progeny emit alpha radiation. It is an isotope of radon gas.

Working level (WL) - the unit of measurement of airborne radon or thoron alpha particles in an area. Working levels are used to express the concentrations of radon daughters in underground mines for compliance sampling. It is calculated by the general formula:

$$WL = \text{Radiation Level X Time (hours)}$$

Working level months (WLM) - the unit of measurement for determining compliance with the annual exposure limit for miners. A lung dose of 10 REM is equal to 1.0 WLM. For compliance determination, 30 CFR § 57.5040 requires WLM be calculated by the following formula:

$$WLM = \frac{\text{Number of hours exposed in a month X average WL}}{\text{173 hours per month}}$$

X-ray radiation - is similar to gamma radiation in that it is a ray and not a particle but different in that it is man-made versus naturally-occurring radiation. X-rays are produced when a focused electron beam is aimed at a Tungsten surface resulting in an emanation of high energy, highly penetrating radiation. Lead or thick concrete can block this type of radiation.

III. Standards Applicable to Ionizing Radiation

A. Exposure Limits

Title 30 CFR §§ 57.5037 through 57.5047 contain the ionizing radiation exposure limits for miners:

1. Miners shall not be exposed to air having a radon daughter concentration exceeding 1.0 working level (WL) in active workings.

2. Ventilation is the primary means for controlling radon daughters to below the allowable exposure limits. However, respirators approved by NIOSH for radon daughters shall be used in atmospheres whose radon daughter concentrations exceed 1.0 WL.

3. If the WL concentration exceeds 10 WL, protection against radon gas shall be provided by supplied air devices or by face masks containing absorbent material capable of removing both radon and its daughters.

4. No miner shall be exposed to more than 4.0 WLM in any calendar year.

5. Annual individual gamma radiation exposure shall not exceed 5 REMs.

B. Sampling requirements

1. Underground Non-Uranium Mines

a. Screening Frequency - Annually sample all metal and nonmetal mines where radon daughters have exceeded 0.1 WL in the past, per 30 CFR § 57.5037(a). Sample remaining nonmetal and stone mines every three years. Sample new or reopened mines as soon as possible. Sample exhausts (return airways) and poorly ventilated areas for radon daughters. Where any screening sample exceeds 0.1 WL, follow the additional procedures below.

b. Concentration 0.1 WL - Sample all active work areas four times annually (Full-Time Permanent - FTP) or whenever conducting a regular inspection (Intermittent - INT). Also evaluate the mine operator's (quarterly) sampling procedures for possible inadequacies.

Monitor mine operator compliance with 30 CFR §§ 57.5037(a)(2), 57.5038, 57.5039, 57.5040(a)(2), 57.5041, 57.5044, 57.5045, and 57.5046 where radon/thoron daughters concentrations exceed 0.3 WL.

Check the mine operator's sampling records and thoroughly sample any work area exceeding 0.3 WL. A mine operator may invoke the five consecutive week provisions of 30 CFR §§ 57.5037 and 57.5040. If MSHA sampling verifies the mine operator's claims that alpha emissions have remained under 0.3 WL, the operator can suspend weekly sampling in favor of quarterly sampling.

However, the mine operator must continue weekly sampling and worker exposure record keeping if MSHA results exceed 0.3 WL.

2. Underground Uranium Mines

a. Sampling Frequency - Sample all active work areas for both radon and thoron daughters four times annually or whenever a regular inspection is conducted. Also, monitor compliance with 30 CFR §§ 57.5037 and 57.5040. Where any sample exceeds 0.1 WL, follow the additional procedures below:

b. **Concentration 0.1 WL** - Evaluate the mine operator's sampling procedures and employee exposure records to verify conformity to the standard.

Monitor mine operator compliance with 30 CFR §§ 57.5037, 57.5038, 57.5039, 57.5041, 57.5044, 57.5045 and 57.5046 where radon daughters concentrations exceed 0.3 WL.

Check the mine operator's sampling records and thoroughly sample the area in question if an operator invokes the five consecutive week provisions of 30 CFR §§ 57.5037 and 57.5040. If MSHA sampling verifies the operator's findings, the mine operator can revert to biweekly sampling. If MSHA sampling results exceed 0.3 WL, however, the operator must continue weekly sampling.

c. **Screening for Gamma Radiation** - Perform annual gamma radiation screening in all underground mines where radioactive ores are mined. Monitor compliance with 30 CFR § 57.5047.

- Average readings in excess of 2 milliroentgens per hour (mR/hr) require implementation of personal dosimeters for all persons affected. Note: 2 milliroentgens per hour is equivalent to 2 millirems per hour.

- Perform calculation presented in Appendix to obtain projected shift exposure. Multiply projected shift exposure by the number of shifts per week if doing a one day screening and divide by 1000 to obtain estimated REM value for a work week. Compare this calculation with records to check the consistency of recorded exposures with calculated exposures. Any significant discrepancy should be investigated.

- Records of cumulative individual exposures should be checked to ensure compliance with 5 REM annual exposure limit.

- Failure to provide personal dosimeters and keep records of cumulative individual exposures are citable offenses when circumstances require, (see item 1 above.)

C. Nuclear Gauges

For those operations that have radiation sources or nuclear gauges, the inspector should:

1. Review the Nuclear Regulatory Commission (NRC) license;

2. Check the provisions of the NRC license during inspections; and

3. If violations are found, inform the office issuing the license.

D. Other Related Standards

56/57.15006 - Protective equipment and clothing for hazards and irritants.
Application: this would apply to high concentrations of alpha radiation (1 WL and above) where respirators are required, and when working around x-ray and gamma radiation where lead vests may be required.

56/57.16003 - Storage of hazardous materials.
Application: gamma sources such as cobalt isotopes must be kept in lead-shielded containers.

56/57.16004 - Containers for hazardous material.
Application: same as 56/57.16003.

56/57.18002 - Examination of workplace.
Application: may apply where nuclear gauges and laboratory assay equipment are in use.

56/57.18006 - New employees.
Application: new employees should be taught best practices for working around nuclear gauges and other radioactive equipment and environments.

56/57.20011 - Barricades and warning signs.
Application: should be placed wherever radioactive sources are used and where background levels of radiation in mine exceed the standard; i.e., 0.3 WL for alpha and 2 mR/hr for gamma.

56/57.20012 - Labeling of toxic materials.
Application: radioactive sources should be clearly labeled as such at all times.

IV. General Sampling Guidelines

The time spent in an area and the radiation concentration in that area are used to calculate a miner's personal exposure. The following table outlines the ionizing radiation sampling instruments available to inspectors:

Table 10-1. Radiation Detection Instruments Used by MSHA

Model Number	Common Name	Company	Radiation Type	Method	Appendix Section
L-2000	Scaler	Ludlum	Alpha*	Kusnetz	I & II
L-2200	Scaler	Ludlum	Alpha*	Kusnetz	I & II
L-1000	Scaler	Ludlum	Alpha*	Kusnetz	I & II
PS-1, PS-2***	Scaler	Eberline	Alpha*	Kusnetz	I & II
PRS-2	Rascal	Eberline	Gamma	DRI**	V
L-2	Geiger-Mueller	Ludlum	Gamma Beta	DRI**	V

*radon
**DRI – Direct Reading Instrument
***being replaced by Ludlums

A. Sampling Non-Uranium Mines

1. Only a few radon samples are necessary for a preliminary evaluation. Sample the main return airways (exhausts) and any poorly ventilated travelways or work areas. If the counts from these samples indicate less than 0.1 WL, it can be assumed that the health hazard does not exist. No further sampling for radon daughters is required for the remaining active working areas. Several samples may be taken before the filters need to be counted.

2. If the radon daughter level in the return exceeds any of the levels in 30 CFR §§ 57.5037 through 57.5047, samples in the active work areas must be collected.

B. Sampling Uranium Mines

1. For radon samples, select locations that are most representative of the miner's average exposure.

2. When in doubt, sample all prominent work stations, giving priority to the face and out of the way work areas**.** Take representative samples in all active stoping areas, travelways, shops, lunch rooms, and other occupied mine areas.

C. Guidelines for Enforcement Sampling For Alpha Radiation

1. Follow the sampling strategies outlined in paragraphs A. and B. above.

2. Check air currents at the sampling locations for unusual conditions, using a smoke-cloud producing apparatus and/or anemometer.

3. Measure and record the ventilation quantity at the time and place of sampling.

4. Take ample notes regarding all conditions which might affect radon daughter concentrations in the areas sampled.

5. Follow good sampling procedures.

6. Take all possible precautions to maintain the integrity of the calibration sampling equipment.

7. Take as many samples as necessary to determine compliance with the applicable standard and to establish an appropriate time limit for the abatement of any citations which are issued.

D. Collecting the Sample

1. Pump and Filter Sampling Combination Kusnetz Method

a. Calibrate sampling pump at 2.0 Lpm or more (up to the stable limit of your personal sampling pump), using the procedures in Chapter 4, and calibrate the readout instrument.

b. Use a 25 mm fiberglass filter (Gelman Type AE). Identify the filter with a unique number gently using a gel type pen, a felt tip pen or soft lead pencil. **Caution**: Handle and write with care; the fiberglass filters are very delicate and easily cracked or broken. The fiberglass filter has a semi-smooth "waffled" pattern side and a rough side. The filter should be placed in the cassette holder with the semi-smooth waffled side facing the sampling pump and the rough side exposed to the mine atmosphere. The sampling set-up is shown in Figure 10-2.

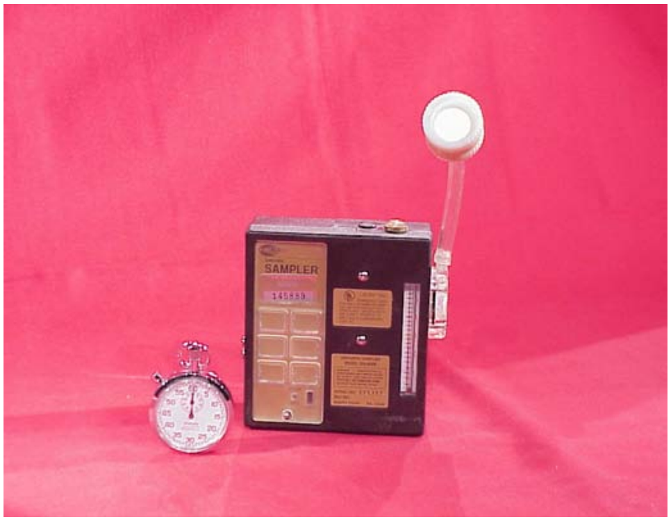

Figure 10-2. Sampling Set-up

c. Turn on sampling pump for 5 minutes.

d. Record in the Health Field Notes (refer to Chapter 21, Section V):

- Time the sampling pump started;
- Pump identification number;
- Miner's name and job title (if personal sample), and work location;
- Shift hours per day and days per week;
- Any respirator worn or expected to be worn (brand, model, type of filters); and
- Whether an acceptable respiratory protection program exists (see Chapter 16 for criteria for evaluating a respiratory protection program).

e. Throughout the shift, record all other pertinent information in the Health Field Notes:

- Controls in use with general description and whether or not they seem adequate;
- Potential sources of exposure, a general description of these sources, number of persons affected, and possible additional control measures;
- Activity of miner, equipment operating in the area, and approximate time spent at each activity; and
- Any other samples taken (e.g., detector tubes, badges, noise, etc.) and results, if available.

f. After the sampling period has ended, turn off the sampling pump, record the time, and place the cassette containing the filter in a safe place for counting. It may be possible to sample several areas before counting.

g. Analyze the sample filters between 40 and 90 minutes after sample has been taken, and record all results.

2. Hand-Held Direct Reading Instruments, i.e., Geiger-Mueller counters.

a. Check battery level.

b. Calibrate sampling instrument.

c. Turn on the instrument and Record in the Health Field Notes:

- Time the instrument turned on and off;
- Instrument identification number;
- Miner’s name and job title (if personal sample), and work location;
- Shift hours per day and days per week;
- Any respirator worn or expected to be worn (brand, model, type of filters); and
- Whether an acceptable respiratory protection program exists (see Chapter 16 for criteria for evaluating a respiratory protection program).

d. Throughout the shift, record all other pertinent information in the Health Field Notes:

- Controls in use with general description and whether or not they seem adequate;
- Potential sources of exposure, a general description of these sources, number of persons affected, and possible additional control measures;
- Activity of miner, equipment operating in the area, and approximate time spent at each activity; and
- Any other samples taken (e.g., detector tubes, badges, noise, etc.) and results, if available.

E. Instructions to the Miner

1. Tell the miner what you are doing, what the sampling device does, and the reason for the sampling (i.e., the hazard). If available, issue a Miner Health Hazard Information Sheet or Card.

2. Emphasize the need for the miner to continue to work in a routine manner and report to you any unusual occurrences during the sampling period.

F. Conditions for Repeat Sampling

The standards do not require more than one sample for the purposes of enforcing safe environmental standards. However, multiple samples are often beneficial, (refer to statements in III.B.1.).

V. Post-Inspection Procedures

A. Review Health Field Notes

Check that you have recorded all necessary information in the Health Field Notes (MSHA Form 4000-31).

B. Post-Inspection Calibration of Sampling Pump

Check the sampling pump, using the procedures in Chapter 4.

C. Post-Inspection Calibration Check of Alpha Detector and Scaler

Check the instrument for proper operation with the alpha assigned source.

D. Post-Inspection Calibration Check of Geiger-Mueller Counter

Check the instrument for proper operation, using the gamma radiation source attached to the side of the detector box.

E. Data Summary Forms (ASDS and PEDS)

When completing the Area Sample Data Summary (ASDS) - refer to Chapter 21, Section IX) or Personal Exposure Data Summary (PEDS) - refer to Chapter 21, Section VIII), be sure that the contaminant code and concentration and exposure limit units of measurements are as follows:

Contaminant Code	Contaminant	Units
801	Alpha Radiation	WL
803	Gamma Radiation	mR/hr

F. Error Factor

The error factor for determining compliance, using radiation instrumentation outlined in the Appendix to this Chapter, is 1.3 (or 30 %).

G. Radon Daughter Sampling Data Form (MSHA Form 4000-21)

Complete this form when sampling is conducted at underground mines for radon daughters using the Filter and Sampling Method (see Figure 10-3).

VI. Recordkeeping

Inspection reports should include a copy of the Health Field Notes, the completed Area Sample Data Summary (ASDS), Personal Exposure Data Summary (PEDS), Radon Daughter Sampling Data Form, citation/orders, and any other supplemental information collected during the inspection.

Figure 10-3. Radon Daughter Sampling Data Form

Radon Daughter
Sampling Data

U. S. Department of Labor
Mine Safety
and Health Administration

Mine Name

Company Name

Date | AR Number | Name

Counter No | Pump No | Filter No

LPM × Sampling Time (min) = Volume

Time of Count − Sample End Time = Elapsed Time (min)

CPM × Efficiency Factor
Volume × Time Factor
= Working Level

Sample Location

Remarks

MSHA Form 4000-21, Mar 79 *Part II — MSHA*

CHAPTER 10 – APPENDIX
RADIATION SAMPLING INSTRUMENTATION

Chapter 10 - Appendix
Radiation Sampling Instrumentation

I. Kusnetz Equipment and Accessories

A. Filter and Cassette

1. Filter - MSHA uses the 25 mm diameter Gelman, Type AE, glass fiber filters for the Kusnetz method of radon and thoron daughters sampling. Keep the filters dry, free of dirt, and intact.

2. Sampling Cassette - Ludlum and Eberline instruments use a two-piece plastic filter holder or cassette which attaches to the pump, usually with surgical rubber or Tygon tubing (refer to Figure 10-2).

B. Sampling Pump

Operation and Calibration - For all methods of radon daughters sampling, MSHA uses personal monitoring pumps that draw at least 2.0 Liters of air per minute (Lpm) through a filter and filter holder. For sampling, all pump by-passes must be closed. Operate and calibrate the pumps in accordance with Chapter 4.

C. Scalers and Detectors

The most common scaler that MSHA uses for counting alpha radiation in the field is the Ludlum Model 2000 (see Figure 10A-1). This model is used when following the Kusnetz method to determine radiation exposure in working levels. The scaler is connected to a detector with a high voltage cable. The most common detectors are the Ludlum 43-9 and the Eberline SPA-1.

Note: After a scaler and a detector are calibrated as a unit, they must not be interchanged with similar pieces from another instrument.

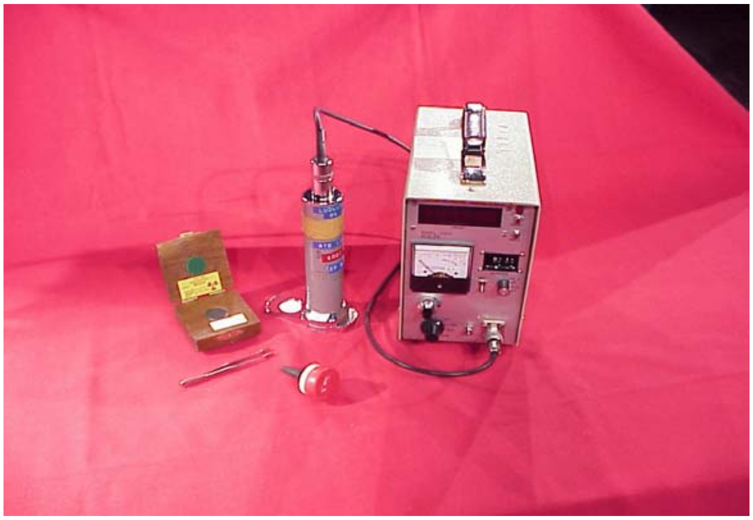

Figure 10A-1. Ludlum 2000 with accessories

D. Accessories

1. Thorium Standard (Th-230)

2. Batteries

   a. Check the battery condition on all instruments before use because low batteries can cause misleading results. For those instruments for which the battery condition cannot be checked before operation, count the Th-230 standard to confirm proper operation.

   b. Alkaline batteries may be used in the instruments, but they cannot be re-charged. Recharging may cause them to explode and corrode the inside of the instrument.

   c. <u>Remove the batteries</u> when an instrument is to be stored more than two weeks, or is sent in for recalibration.

3. Rechargeable Batteries

   a. Ludlum instrument rechargeable batteries have a trickle charger and should be left on charge whenever possible. Eberline instrument batteries require 100 hours for an initial full charge, and should not be overcharged. Nickel-Cadmium (NiCad) batteries have an almost indefinite life, if they are fully discharged and then fully recharged occasionally.

b. Operate all instruments on battery power only.

4. High Voltage Connections

a. Keep all connections between the high voltage cord and the scaler and detector clean.

b. Do not adjust high voltage screws and discriminator screws. These are for calibration adjustments only.

E. Calibration Policy

1. Periodic Calibration

Field alpha counters are calibrated by the Physical and Toxic Agents Division, Pittsburgh Safety and Health Technology Center. Instruments need to be recalibrated whenever the following occurs:

a. The instrument has been repaired;

b. The Th-230 source count rate consistently deviates by more than 10% of the count obtained at the time of calibration; or

c. Six months have elapsed since the last calibration.

For calibration send instruments to:
MSHA Laboratory
PSHTC Alpha Detector Calibration
Cochrans Mill Rd, Bldg 38
P.O. Box 18233
Pittsburgh, PA 15236
Ph. 412-386-6984

2. Calibration Check

a. Before and after counting a batch of field samples, check instrument reliability by counting the Th-230 standard in the detector for one minute. Do not move the instruments during counting. If the instrument is operating properly, the count rate obtained with the standard should be within ± 10 % of the average count rate obtained at the time of calibration.

b. To ensure that an instrument is operating properly, first count the Th-230 standard and then get a count with nothing in the detector slide (background count). The background count rate should be less than 5 counts per minute (cpm). If the background level is too high, contact the District Office for guidance.

c. Keep the Th-230 standard clean and touch only the edges or back side of the disk. Dirt or oil deposited on the front side of the disk may affect the performance of the check standard.

d. The back side of the standard has a serial number on it. Store the standard with the back side up (shiny side down).

F. Warnings - Electrical Noise

1. Do not use the instruments near power supplies such as electric generators. Electrical noise may be picked up by the instruments.

2. Obtain a background count at the sampled location to check for electrical noise.

II. Kusnetz Sampling Method

A. Radon Daughters/Progeny Working Levels

1. Calibrate the pump to draw 2.0 Lpm or more with a representative filter and filter holder in line. <u>Higher flow rates improve the counting statistics and should be used whenever possible</u>. Pump calibration procedures are provided in Chapter 4 of this Handbook.

2. Number each filter with a gel type pen, a felt tip pen or a soft lead pencil and each filter cover cap and holder before sampling. With a filter in place, assemble the filter holder snugly to ensure that air will not leak around the filter during sampling. The woven pattern side of the filter is the back side (downstream) and should be placed against the screen half of the cassette.

3. Carry several pre-loaded and numbered filter holders to the mine.

4. Choose the location(s) to be sampled before beginning the survey.

5. Assemble the sampling train. Connect the filter holder with the open face away from the pump (upstream).

6. Start both the pump and the stopwatch at the same time.

7. Time each sample for exactly 5 minutes.

8. Place the contaminated filter in a safe location until it is counted 40 to 90 minutes later. Leaving the filter in the cassette until counting is acceptable.

9. More samples may be taken before counting, if time allows.

10. Before and after counting a batch of filters, check the counter reliability by counting the Th-230 source supplied with the counter.

11. For radon daughters, each sample must be counted 40 to 90 minutes after the end time of the sample. To improve accuracy, the count time can be two or more minutes. For long count times, use the midpoint of the counting time when determining the time factor used in the formula noted in 12 below. The count rate used in the calculation is the total of the counts indicated divided by the number of minutes of counting.

12. The radon daughters working level is calculated by completing MSHA Form 4000-21. The formula used on the form is shown below:

$$WL = \frac{CPM \times EF}{Vol \times TF}$$

Where:

WL	=	radon daughters concentration in working levels
CPM	=	count rate of sample in counts per minute
EF	=	efficiency factor of counter indicated on probe
Vol	=	total sample volume in liters
TF	=	time factor from Table 10A-2

13. Complete **Radon Daughter Sampling Data Form** (MSHA Form 4000-21). Be sure to include the following under Remarks on MSHA Form 4000-21:

- Number of workers at location sampled;
- Description of work being performed or equipment operating;
- Respirator usage and approval number; and
- Ventilation conditions (estimated air volume).

14. Report sampling on Area Sampling Data Summary Sheet, MSHA Form 4000-42

Table 10A-2. Time Factor for Calculating Radon Daughters/Progeny Working Levels

Elapsed time after sampling, minutes	Time Factor	Elapsed time after sampling, minutes	Time Factor	Elapsed time after sampling, minutes	Time Factor
40	150	57	116	74	84
41	148	58	114	75	83
42	146	59	112	76	81
43	144	60	110	77	80
44	142	61	108	78	78
45	140	62	106	79	77
46	138	63	104	80	75
47	136	64	102	81	74
48	134	65	100	82	72
49	132	66	98	83	71
50	130	67	96	84	69
51	128	68	94	85	68
52	126	69	92	86	66
53	124	70	90	87	65
54	122	71	89	88	63
55	120	72	87	89	62
56	118	73	86	90	60

B. Thoron Daughters/Progeny Working Levels

1. Repeat steps 1 through 10 in Section I.A above. The time for collecting the sample may be more than 5 minutes and the same volume over 50 L of air when sampling for only thoron daughters. A simple thoron screening may be done with as little as 10 L of air which permits using the filters counted earlier for radon.

2. For thoron daughters, each sample count must be performed between 5 and 17 hours after the end of the sample collection period. Saving the radon daughters filters after counting them is therefore necessary. To improve accuracy, the counting period time should be 5 or more minutes.

3. The thoron daughters working level is now calculated by completing MSHA Form 4000-21; however, a <u>different time factor</u> table is used for thoron daughters than is used for radon daughters. The formula used on MSHA Form 4000-21 is:

$$WL = \frac{CPM \times EF}{Vol \times TF}$$

Where: WL = thoron daughters concentration in working levels

CPM = count rate of sample in counts per minute

EF = efficiency factor of counter

Vol = total sample volume in liters

TF = time factor from Table 10A-3

4. When mixtures of thoron and radon daughters are found, the radon daughters concentrations obtained by the Kusnetz method must be corrected. The values that must be subtracted from the radon daughters concentrations are listed in Table 10A-4. Once it has been determined that thoron is not a factor in a given mine, it is not necessary to screen for thoron each time radon samples are taken; every two to three years should be adequate.

Table 10A-3. Time Factors for Calculating Thoron Daughter Working Levels

Elapsed time after sampling, hours	Time factor	Elapsed time after sampling, hours	Time factor	Elapsed time after sampling, hours	Time factor
5.0	13.00	9.0	9.95	13.0	7.75
5.2	12.84	9.2	9.83	13.2	7.65
5.4	12.67	9.4	9.71	13.4	7.55
5.6	12.52	9.6	9.59	13.6	7.45
5.8	12.36	9.8	9.47	13.8	7.35
6.0	12.20	10.0	9.35	14.0	7.25
6.2	12.03	10.2	9.24	14.2	7.16
6.4	11.86	10.4	9.13	14.4	7.07
6.6	11.69	10.6	9.02	14.6	6.98
6.8	11.52	10.8	8.91	14.8	6.89
7.0	11.35	11.0	8.80	15.0	6.80
7.2	11.21	11.2	8.69	15.2	6.71
7.4	11.07	11.4	8.58	15.4	6.62
7.6	10.93	11.6	8.47	15.6	6.53
7.8	10.79	11.8	8.36	15.8	6.44
8.0	10.65	12.0	8.25	16.0	6.35
8.2	10.51	12.2	8.15	16.2	6.25
8.4	10.37	12.4	8.05	16.4	6.15
8.6	10.23	12.6	7.95	16.6	6.05
8.8	10.09	12.8	7.85	16.8	5.95
----	----	----	----	17.0	5.85

C. Example of Calculations

1. Computing Radon Daughters/Progeny Working Levels (WL, Kusnetz)

   a. Sample volume (Vol) = 2.1 Lpm x 5 min. = 10.5 liters.

   b. Efficiency factor of the counter (EF) = 3.3 (factor, labeled on each scaler or detector).

   c. Time at beginning of sample = 10:10.

   d. Time at end of sample = 10:15.

   e. Time of counting = 11:05.

   f. Count rate (CPM) = 260 CPM.

      Note: For count time of over 1 minute, CPM = total count/count time (min)

   g. Elapsed time between end of sample and time of counting = 50 minutes (10:15 to 11:05).

   h. Time factor (TF) = 130 (from Figure 10A-2).

   i. Radon Daughters WL =

$$\frac{\text{CPM x EF}}{\text{Vol x TF}} = \frac{260 \times 3.3}{10.5 \times 130} = 0.63 \text{ WL}$$

2. Computing Thoron Daughters Working Levels (WL, Kusnetz)

   a. Sample volume (Vol) = 2.1 Lpm x 5 min. = 10.5 liters

      Note: Take a longer sample if <u>only</u> thoron daughters are to be measured (sample up to 1 hour).

   b. Counter efficiency factor (EF) = 3.3.

      Note: This is the same EF as used for radon daughters.

   c. Time at beginning of sample = 10:10.

d. Time at end of sample = 10:15.

e. Time of counting = 16:15 (16:11 to 16:18).

Note: Use midpoint of the counting time of count if count is longer than 1 minute.

f. Count rate (CPM) = 23 counts/7 min = 3.3 CPM.

Note: For count time of over 1 minute, CPM = total count/count time (min).

g. Elapsed time between end of sample and time of counting = 6.0 hours (10:15 to 16:15).

h. Time factor (TF) = 12.20 (from Figure 10A-3).

i. Thoron Daughters WL =

$$\frac{\text{CPM x EF}}{\text{Vol x TF}} = \frac{3.3 \text{ x } 3.3}{10.5 \text{ x } 12.20} = 0.08 \text{ WL}$$

3. Computing Mixtures of Radon and Thoron Daughters (WL, Kusnetz)

a. Compute radon daughters concentrations as in C.1.a through h. above.

b. Compute thoron daughters concentrations as in C.2.a through i. above.

c. Correct radon daughters concentration for thoron daughters present during radon daughters count by reducing radon daughters WL by factor in Figure 10A-4. For example:

Radon daughters concentration = 0.63 WL at 50 minutes

Thoron daughters concentration = 0.08 WL at 6.0 hours

Correction from Figure 10A-4 = 0.02 WL

Corrected radon daughters WL = 0.63 - 0.02 = 0.61 WL

d. Total exposure rate =
radon daughters WL + thoron daughters WL = 0.61 + 0.08 =
= 0.69 WL

Table 10A-4. Reduction of Radon Daughter Concentrations (WL) for Thoron Daughters Present

Measured thoron daughter concentration, WL	Radon daughter count time, minutes					
	40	50	60	70	80	90
0.1	0.01	0.02	0.02	0.02	0.03	0.03
0.2	0.02	0.02	0.03	0.03	0.04	0.05
0.3	0.03	0.04	0.05	0.06	0.07	0.08
0.4	0.04	0.05	0.06	0.08	0.08	0.10
0.5	0.05	0.06	0.07	0.09	0.11	0.13
0.6	0.07	0.08	0.09	0.11	0.13	0.17
0.7	0.08	0.09	0.11	0.12	0.15	0.18
0.8	0.09	0.11	0.12	0.14	0.17	0.22
0.9	0.10	0.12	0.14	0.17	0.20	0.23
1.0	0.11	0.13	0.15	0.19	0.23	0.28
1.2	0.13	0.15	0.18	0.22	0.25	0.32
1.4	0.15	0.18	0.21	0.26	0.31	0.37
1.6	0.18	0.21	0.24	0.29	0.35	0.43
1.8	0.20	0.23	0.27	0.32	0.39	0.48
2.0	0.23	0.25	0.30	0.37	0.43	0.53

III. Gamma and X-Ray Radiation Sampling

For those operations that have radiation sources and nuclear gauges, the inspector should review the Nuclear Regulatory Commission (NRC) license. These sources and gauges typically emit gamma radiation or X-rays. The inspector should check the provisions of the NRC license during inspections. If violations of the license agreement are found, the inspector should inform the office issuing the license and the company radiation safety officer (RSO), if one is designated in the license. If the inspector has questions about a particular license, the NRC lists the following toll-free numbers:

Region 1 (Northeastern states)	- 800-432-1156
Region 2 (Southeastern states)	- 800-577-8510
Region 3 (North Central states)	- 800-522-3025
Region 4 (All other states)	- 800-952-9677
24-hour emergency hotline	- 301-816-5100

To sample for gamma and X-Ray radiation, MSHA inspectors presently use the Ludlum Model L-2 Geiger-Mueller scaler:

A. Operation Check

1. Slide the battery box button to the rear and open the lid. Do not twist the lid button; it slides to the rear. Install two size “D” alkaline batteries. Note (+) and (-) marks on the inside of the lid. Match the battery polarity to these marks.

   Note: Center post of size “D” battery is positive.

2. Close the battery box lid.

3. Move the range switch to BAT. The meter should deflect to the battery check portion of the meter scale. If the meter does not respond, recheck that batteries have proper polarity.

4. Connect the cable to the instrument and detector.

5. Turn the instrument range switch to X10. Expose the detector to the check source. The speaker should click with AUDIO ON-OFF switch to ON.

6. Move range to lower scales until the meter reading is indicated. The toggle switch labeled “F - S” should have fast response in “F,” slow response in “S.”

7. Depress the RES switch. The meter should zero.

8. Proceed to use the instrument.

Note: Never store the instrument more than 30 days without removing batteries. Although this instrument will operate at very high ambient temperatures, battery seal failure can occur at 100° F.

B. Procedure

Using the Geiger-Mueller Ludlum, walk slowly around the work area at a steady pace and obtain an average of the meter readings. Record this average and the high and low readings for the work area.

C. Gamma Radiation Exposure Calculations

- To calculate gamma radiation exposure, multiply the number of hours of exposure (the amount of time the worker is expected to remain in the area) by the exposure rate (mR/hr) of the area.
- If taking samples over a period of days such as a working week, add the daily exposures together to obtain the miner’s cumulative exposure for the given time period.
- Divide mR by 1000 to convert to REMs.
- This calculated exposure level provides an estimate of a typical exposure in that working area for a given period of time. The inspector can then compare the calculated value with the company’s individual exposure records. Differences greater than 10% should be investigated.