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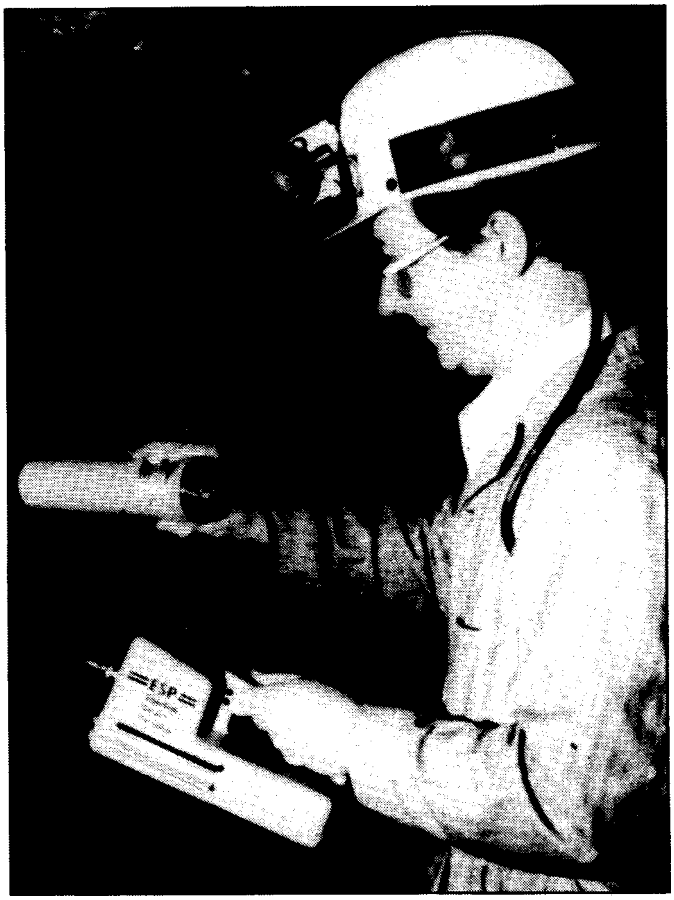
# Evaluation of Several Natural Gamma Radiation Systems-A Preliminary Study




UNITED STATES DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES

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***Cover photograph: Researcher using natural gamma radiation sensor underground.***

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# Evaluation of Several Natural Gamma Radiation Systems-A Preliminary Study

By S. D. Maksimovic and G. L. Mowrey

UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES
Rhea Lydia Graham, Director

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## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| | | | |
|---|---|---|---|
| Btu/lb | British thermal unit per pound | MeV | mega electron volt |
| cm | centimeter | m | meter |
| cpm | count per minute | m/min | meter per minute |
| cps | count per second | mA | milliampere |
| ft | foot | mm | millimeter |
| ft/min | foot per minute | s | second |
| g | gram | st | short ton |
| h | hour | V | volt |
| in | inch | μCi | microcurie |
| keV | kilo electron volt | μs | microsecond |
| kg | kilogram | °C | degree Celsius |
| lb | pound | °F | degree Fahrenheit |

Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

# EVALUATION OF SEVERAL NATURAL GAMMA RADIATION SYSTEMS-A PRELIMINARY STUDY

By S. D. Maksimovic[1] and G. L Mowrey[1]

## ABSTRACT

An important element of the U.S. Bureau of Mines (USBM) mining research program is the development and evaluation of reliable coal interface detection (CID) systems. Commercially available CID sensors based on natural gamma radiation (NGR) are only applicable if the immediate roof is composed of shaley material. The USBM has made numerous underground and laboratory measurements using several NGR systems approved for installation on mining machines by the Mine Safety and Health Administration. In addition, two small handheld NGR instruments were used to make comparative measurements. Underground NGR measurements in 10 different coal seams, potassium-uranium-thorium radiometric analyses on samples from 16 seams, and chemical analyses of coal and rock for correlation with NGR counts were made. Laboratory test results on the effect of airgap and sample thickness, size, and weight on the NGR measurements, as well as general results of the various NGR systems, are discussed.

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# INTRODUCTION

To help evaluate the usefulness of the natural gamma radiation (NGR) technique for the coal interface detection (CID) project, the U.S. Bureau of Mines (USBM) collected data from various mining companies conducting underground and surface operations in 15 major and 110 minor coal seams in the United States (*1*).[2] This work was done in support of the USBM goal to improve the method of recovering coal from the nation's mines in a safe and economical *manner*. Field visits were made to eight mines with underground operations in three major and four minor coal seams in different coal regions. Underground tests were made of three commercially available NGR-based coal thickness measurement systems (RHC 801, RHC 803, and AME 1008) that have been approved for installation on mining machines by the Mine Safety and Health Administration (MSHA). A fourth MSHA-approved sensor, the AME 1016, was not available for testing. Over 200 coal and rock samples have been collected from these mines for standard coal laboratory analyses (i.e., ash, sulfur, and heating value). Project personnel measured the NGR of these samples using two handheld radiation survey instruments (ESP-2 and GRS-500). Also, 45 coal and rock samples, representing 16 coal seams, were analyzed for bulk density, potassium, uranium, and thorium, using radiometric testing methods. It should be noted that the handheld instruments can only be used in fresh air since they have not been approved as intrinsically safe. General descriptions of these NGR systems and results of selected underground and laboratory tests are given in this report.

## GENERAL DESCRIPTION OF NGR SYSTEMS

The NGR technique measures naturally occurring gamma radiation found in underground strata. Shales, clays, silts, and muds typically have higher levels of naturally occurring radioactivity than coal, sandstone, and limestone. This is because minute quantities of radioactive potassium, uranium, and thorium are nearly always deposited during the formation of the shaley materials. Therefore, overlying and/or underlying shale strata act as the NGR source, and intervening coal is an NGR absorber whose thickness can be determined by the amount of NGR attenuation.

Two vendors, Rowe Hankins Components, Ltd. (RHC), of Lancashire, England [formerly known as Salford Electrical Inc. (SEI)] and American Mining Electronics (AME) of Huntsville, AL, fabricate MSHA-approved NGR systems for mining equipment. RHC currently manufacture Models 801 and 803 natural gamma coal thickness indication systems. These RHC units have been used on longwall shearers and continuous miners in underground applications, and also on highwall miners in surface applications. The readouts of the two RHC units consist of a column of light emitting diodes (LED's), each of which represents 20 mm (0.75 in) of roof coal. Over 150 of these RHC systems are in use worldwide, the majority in England but some are used in the United States on highwall miners and longwall shearers.

AME makes similar NGR systems, the AME 1008 and AME 1016. The AME 1008 and AME 1016 use LED's to provide numerical output that directly gives the thickness in inches of roof coal remaining. They have been successfully used in numerous underground mining operations in the United States on both continuous miners and longwall shearers (2).

Two small handheld radiation survey instruments (Eberline ESP-2 and EDA GRS-500) were used at selected mine sites for evaluating the applicability of the NGR technique. Since these units are not intrinsically safe they must be used only in fresh air. They are also used for NGR laboratory testing of coal and rock samples. Details of specific sensors and radiation survey instruments follow. Technical specifications of the NGR systems evaluated in this report are given in the appendix.

### RHC MODEL 801

The RHC Model 801 NGR sensor (probe) (3) uses a scintillation detector [NaI (Tl) crystal] that is rugged and can be mounted on the face side of any coal-cutting machine (figure 1). According to the manufacturer, it can reliably sense between 0 and 500 mm (0 and 19.5 in) of coal thickness in the present or previous cut or prior to cutting. The RHC S01 coal thickness indicator (CTI) unit is connected to the RHC 801 probe and provides the machine operator with an indication of the deviation from required roof or floor coal thickness (figure 2). The horizon (required coal thickness) can be set anywhere in the range from 0 to 500 mm (0 to 19.5 in), the deviation being indicated by LED's in multiples of 20 mm (0.75 in) up to a maximum of ±80 mm (3.1 in). There are presently three electrically identical intrinsically safe (IS) power supplies. The mechanical arrangement of the components is different to allow for fitting into different sired spaces.

[2] *Italic* numbers in parentheses refer to items in the list of references preceding the appendix at the end of thii report.

An optional remote indicator unit provides a secondary set of LED's indicating any error in coal thickness from the horizon setting (figure 3). This unit, powered by the CTI unit, can be added to the system if needed (e.g., for double-ended longwall shearer machines).

A block diagram of the RHC 801 coal thickness system is given in figure 4.

## RHC MODEL 803

The RHC Model 803 unit looks basically identical to the RHC 801, except that it is smaller (figure 5). It was developed to fit on smaller mining equipment, e.g., continuous miners.[3]

The main difference between the RHC 803 and the original RHC 801 is a different method of isolation. Also, a circuit board in the 801 unit for an analog and reverse-analog output that had never been used was removed from the 803; both units now have only digital outputs. Both units have been approved. by MSHA for intrinsic safety (approval No. IA-371).

## AME MODELS 1008 AND 1018

The AME Model 1008 coal thickness sensor uses a scintillation detector [NaI (Tl) crystal]. It is a high-performance NGR system containing a large-area gamma detector that accurately measures coal left on the roof or floor when the seam-boundary material contains gamma-producing elements. The system works extremely well in areas where gamma emissions are relatively constant at the mining site and is applicable to both longwall and continuous mining machines (4). The sensor assembly is housed in an explosion-proof (X-P) enclosure that has a window to receive NGR from the rock at the coal-seam boundary. When the window is pointed at the roof or floor area to be measured, the total gamma emission entering the window is directly related to the thickness of coal left at the rock boundary (figure 6).

An IS control and display unit converts gamma counts from the sensor into inches of coal (figure 7). Figure 8 is a block diagram of the AME 1008 coal thickness system and figure 9 shows the physical size comparison between the RHC 803, RHC 801, and AME 1008 natural gamma sensors.

The larger system (AME 1016) has a sensitive NAl crystal that is 33% larger and is capable of measuring up to 890 mm (35 in) of coal with sufficient NGR counts It can be connected to the existing system replacing only the sensor unit on the boom (4). However, this system was not available for evaluation for this report.

## EBERUNE ESP-2

The Eberline Smart Portable (ESP-2) radiation survey instrument, manufactured by Eberline Instrument Corp., Santa Fe, NM, is a handheld unit designed for routine radiation surveys (figure 10). It can also be used in remote areas, operated solely by a computer. The unit utilizes a scintillation detector [NaI (Tl) crystal] to measure NGR in both the field and laboratory (figure 11). It is also equipped with a single-channel pulse height analyzer (PI-IA). Information provided by this instrument is used to determine if the NGR technique is applicable at a given mine and seam (5). Because of the high voltage (500 to 2,450 V) needed by the photomultiplier tube, the ESP-2 is not intrinsically safe; therefore, it must only be operated in fresh air when NGR measurements are taken underground

## EDA GRS_500

The GRS-500 differential gamma ray spectrometer-scintillometer is manufactured by EDA Instruments Inc., Toronto, Canada (figure 12). This instrument is a compact, portable, lightweight, 5-channel field spectrometer that uses both a wideband and a narrowband spectrometer. The wideband spectrometer (a sensitive scintillometer) is used for general reconnaissance. It measures total gamma-ray activity from the uranium series, as well as emitters from the naturally occurring thorium series and potassium (6). Like the ESP-2, the information provided by this instrument is used to determine if the NGR technique is applicable at a given mine and seam. Also, the GRS-500 is not intrinsically safe because of the high voltage (500 to 2,450 V) needed by the photomultiplier tube; therefore, it must only be operated in fresh air when NGR measurements are taken underground.

# NGR EVALUATION TESTS

A series of NGR measurements and geological sam-, ple collections (coal, rock) have been made in the three main geological provinces (Eastern, Interior, and Rocky Mountain) at eight underground mines located in three major and four other coal seams. Results of potassium-uranium-thorium (KUT) radiometric analyses and results of chemical analyses of laboratory testing of coal and rock for possible correlation with NGR counts and other CID sensor measurements, are reported.

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[1]Ptasnik, L. (President, Mine and Process Service Inc., Kewanee, IL) personal communication, 1992.

## PITTSBURGH COAL SEAM

In the Pittsburgh Coal Seam, numerous NGR readings have been made with three commercially available machine-mounted NGR units (RHC 801, RHC 803, and AME 1008), as well as two handheld units (Eberiine ESP-2 and EDA GRS-500), at selected locations underground at the roof mid-seam, floor, and air, in the USBM Safety Research Coal Mine (SRCM). The coal seam in the study area is about 1,674 mm (66 in) thick. The immediate roof strata are composed of shale, up to 610 mm (24 in) thick, followed by draw slate. Due to poor roof conditions, the immediate roof is generally removed. The immediate floor is water-sensitive soft fireclay. One parting of variable thickness is typically found in the seam.

### Effect of Airgap Distance on NGR

Underground testing using these NGR systems was done to investigate the effect of the airgap between the formation surface being measured and the NGR detector. Readings were made at different points by locating the NGR sensor at 76, 152, 305, and 1,219 mm (3, 6, 12, and 48 in) from the roof (shale), face (coal), and floor (fireclay) surfaces and also in the middle of the entry (air).

Figure 13 shows the variation of the NGR readings in the entry, as the NGR detector (ESP-2) is moved away from the surface of roof, coal, and floor. At 76 mm (3 in) from the coal on the right rib, the NGR reading increased 21% with respect to the reading taken with the unit at contact with the coal. In general, for the coal, the NGR reading increased most rapidly during the first 152 mm (6 in), ranging from 16% to 31% increase. At 305 mm (12 in), the total increase ranged from 22% to 54%. For roof shale, at 76 mm (3 in) from the surface, the reading decreased 3%; at 152 mm (6 in), the reading decreased by 10%; and at 305 mm (12 in), the reading decreased by 17%. In general, the NGR readings decreased considerably during the first 305 mm (12 in), approaching the background air reading at a distance of 1,219 mm (48 in). For floor fireclay, the NGR reading decreased mostly during the first 76 to 152 mm (3 to 6 in) from the surface. For 152 to 305 mm (6 to 12 in), the decrease was insignificant (3% to 12%). By increasing the distance of the detector from the coal or rock strata surface by 3% to 12%, the influence of NGR from the surface was found to decrease. At a distance of 305 to 381 mm (12 to 15 in) from the source, the NGR rate was found to be similar to the ambient background NGR rate (combined influence of roof, coal, and floor strata) (table 1).

### Underground Coal Thickness Measurements

Underground NGR readings in the SRCM were conducted using the RHC 801, RHC 803, AME 1008, ESP-2, and GRS-500 sensors. Five slots of different coal thicknesses were prepared by leaving from 0 to 305 mm (0 to 12 in) of coal on the floor. Table 2 shows the general trend of how the gamma-ray counts are attenuated as a function of coal thickness left on the roof and floor, and airgap below-the-roof coal or above-the-floor coal. As the distance increased from 0 to 381 mm (0 to 15 in), the NGR readings slightly increased during the first 229 mm (9 in) when using the ESP-2, and then decreased as the distance from the floor increased. The NGR readings for the ESP-2 were not always consistent. For 0 to 76 mm (0 to 3 in) of coal left on the floor, the NGR readings using the RHC 801 decreased as the distance from the floor clay and coal inaeased from 0 to 381 mm (1 to 15 in). For 152,229, and 305 mm (6,9, and 12 in) of coal left on the floor the NGR readings for the RHC 801 unit generally increased slightly as the airgap above the coal increased from 0 to 229 mm (0 to 9 in). It should be noted that for 0, 76, and l52 mm (0, 3, and 6 in) of coal left on the floor and airgaps of 0 to 229 mm (0 to 9 in), the NGR readings of the RHC 803 were from 10% to 20% higher than those of the RHC 801.

**Table 1.--Effect of airgap distance from a geological surface on NGR count rate (cpm) as measured underground**

**(Pittsburgh Coal Seam)**

| Airgap, mm | (in) | Roof shale | Coal | Floor fireclav | Back-around[1] |
|---|---|---|---|---|---|
| 0 | (3) . . . . . . | 10,267 | 3,670 | a,377 | 6,600 |
| 76 | (6) | 9,917 | 4,447 | a,573 | 6,600 |
| 152 | | 9,200 | 4,493 | 7,520 | 6,600 |
| 305 | (12)' : : : : | a,493 | 4,937 | 7,410 | 6,600 |
| 1,219 | (48) . . . . | 6,813 | 6,110 | 6,820 | 6,600 |

[1]As measured in air in the middle between the floor and roof.

With airgap from 0 to 229 mm (0 to 9 in), the NGR for the AME 1008 was 2.02 times greater than the RHC 803 for 152 mm (6 in) of coal left on the floor, to 2.73 times for 0 mm (0 in) of coal on the floor. When compared with the RHC 801, the NGR readmgs for the AME unit were from 2.42 times to 3.16 times greater for the same measurements. The NGR readings of the RHC 803 were 4% to 18% higher when compared with the RHC 801 (table 2).

### Variability of NGR Readings for a Given Formation

Figure 14 shows the variation of the NGR rates along a 8.53-m (28~ft) long entry of the SRCM. NGR readings using the **ESP-2**[4] were done at 1.22-m **(4-ft)** intervals for

[4]The ESP-2 unit was used with a 6.4-mm (0.25-in) thick lead shield on a detector. By using this lead shield on the detector, the roof-to-coal ratio increased up to 38% and the floor-to-coal ratio increased up to 32%.

the roof, coal, and floor strata of the left rib, face, and right rib (table 3).

**Table 2.—Effect of airgap distance on NGR count rate (cpm) for various thicknesses of floor coal as measured underground**

(Pittsburgh Coal Seam)

| Airgap, mm | (in) | ESP-2 | RHC 801 | RHC 803 | AME 1008 | GRS-500 |
|---|---|---|---|---|---|---|
| | | 0 mm (0 in) coal on floor | | | | |
| 0 | (0) . . . | 7,517 | 12,936 | 11,904 | 35,301 | 17,328 |
| 76 | (3) . . . | 6,873 | 12,960 | 11,712 | 34,243 | 14,678 |
| 229 | (9) . . . | 5,677 | 11,508 | 9,774 | 30,912 | 12,768 |
| 381 | (15) . . | 4,930 | 10,686 | 9,816 | 27,500 | 11,674 |
| | | 76 mm (3 in) coal on floor | | | | |
| 0 | (0) . . . | 5,167 | 9,564 | 8,898 | 24,633 | 12,830 |
| 76 | (3) . . . | 3,233 | 9,300 | 8,940 | 24,919 | 11,692 |
| 229 | (9) . . . | 3,050 | 9,186 | 8,472 | 23,352 | 10,522 |
| 381 | (15) . . | 2,887 | 8,472 | 8,064 | 22,634 | 10,106 |
| | | 152 mm (6 in) coal on floor | | | | |
| 0 | (0) . . . | 3,580 | 6,852 | 5,550 | 15,079 | 9,818 |
| 76 | (3) . . . | 3,620 | 6,666 | 6,426 | 15,600 | 9,636 |
| 229 | (9) . . . | 3,477 | 7,038 | 6,594 | 16,024 | 9,794 |
| 381 | (15) . . | 3,437 | 7,806 | 6,780 | 17,791 | 9,918 |
| | | 229 mm (9 in) coal on floor | | | | |
| 0 | (0) . . . | 3,097 | 6,078 | 5,700 | 13,601 | 8,850 |
| 76 | (3) . . . | 3,233 | 6,402 | 6,114 | 14,112 | 8,682 |
| 229 | (9) . . . | 3,051 | 6,576 | 6,336 | 14,043 | 8,242 |
| 381 | (15) . . | 2,887 | 7,044 | 6,756 | 14,265 | 8,076 |
| | | 305 mm (12 in) coal on floor | | | | |
| 0 | (0) . . . | 2,250 | 4,410 | 3,600 | 9,015 | 6,984 |
| 76 | (3) . . . | 2,343 | 4,614 | 3,852 | 9,868 | 7,444 |
| 229 | (9) . . . | 2,520 | 6,120 | 4,698 | 12,340 | 7,886 |
| 381 | (15) . . | 2,400 | 6,342 | 5,226 | 15,461 | 8,098 |
| | | Background[1] | | | | |
| | | 7,417 | 11,598 | 11,814 | 31,385 | 15,906 |

[1]As measured in air in the middle between the floor and roof.

NOTE.—Measurements taken in the USBM SRCM.

When roof, coal, and floor samples obtained from the same area were measured in the laboratory, a R:C ratio of 2.35 and a F:C ratio of 2.05 were indicated for the right rib, comparing favorably to the data obtained underground.

**Table 3.—Variation of NGR count rates (cpm) as measured along underground coal face and adjacent ribs**

(Pittsburgh Coal Seam)

| Distance from face, mm | (ft) | Roof | Coal | Floor | Background[1] |
|---|---|---|---|---|---|
| | | Right rib | | | |
| 0 | (0) . . . . . . . | 9,330 | 3,100 | 7,500 | 3,470 |
| 1.22 | (4) . . . . . . . | 10,060 | 4,200 | 8,370 | 5,900 |
| 2.44 | (8) . . . . . . . | 11,370 | 4,370 | 8,240 | 6,450 |
| 3.66 | (12) . . . . . . | 10,300 | 4,290 | 8,540 | 6,820 |
| 4.88 | (16) . . . . . . | 10,900 | 4,810 | 8,280 | 6,780 |
| 6.10 | (20) . . . . . . | 11,030 | 4,830 | 8,130 | 7,190 |
| 7.32 | (24) . . . . . . | 11,070 | 4,760 | 8,510 | 7,310 |
| 8.53 | (28) . . . . . . | 11,100 | 5,380 | 8,620 | 7,020 |
| | | Face | | | |
| 0 | (0) . . . . . . . | 10,670 | 3,050 | ND | ND |
| 0.91 | (3) . . . . . . . | 10,530 | 3,860 | 6,790 | ND |
| 2.13 | (7) . . . . . . . | 9,240 | 3,550 | 7,250 | ND |
| 3.35 | (11) . . . . . . | 9,320 | 3,630 | 7,500 | ND |
| 4.57 | (15) . . . . . . | 9,330 | 3,100 | 7,500 | ND |
| | | Left rib | | | |
| 0 | (0) . . . . . . . | 9,890 | 4,600 | ND | ND |
| 1.22 | (4) . . . . . . . | 9,890 | 4,130 | ND | ND |
| 2.44 | (8) . . . . . . . | 9,180 | 3,590 | ND | ND |
| 3.66 | (12) . . . . . . | 11,170 | 3,900 | ND | ND |
| 4.88 | (16) . . . . . . | 9,980 | 3,950 | ND | ND |
| 6.10 | (20) . . . . . . | 9,380 | 3,950 | ND | ND |
| 7.32 | (24) . . . . . . | 9,020 | 3,810 | ND | ND |
| 8.53 | (28) . . . . . . | 10,670 | 3,050 | ND | ND |

ND No data.
[1]As measured in air in the middle between the floor and roof.

NOTE.—Measurements taken in the USBM SRCM.

For the left rib, the mean reading for eight points was 9,900 cpm for roof shale and 3,870 cpm for coal. The mean reading for the right rib over a corresponding distance for shale was 10,640 cpm and for coal was 4,470 cpm. The right rib reading is 7% higher for the roof shale and 16% higher for coal.

For the face, the mean NGR reading obtained at five points was 9,820 cpm for roof shale, 3,440 cpm for coal, and 7,260 cpm for floor fireclay. For the right rib, the mean reading for floor fireclay was 8,300 cpm.

The mean NGR reading for the main roof at eight points, which is about 0.61 m (2 ft) above the coal, was 6,030 cpm. The mean roof-to-coal (R:C) ratio for the left rib was 2.56; for the face it was 2.85; for the right rib it was 2.38. For the floor strata, the floor-to-coal (F:C) ratio was lower, 2.11 for the face and 1.86 for the right rib.

The mean ambient background air NGR rate at eight points in the center of the entry cross-section was 6,340 cpm, which is about 15% lower than the mean value of 59 readings of the surrounding roof, coal, and floor combined (7,280 cpm).

## Laboratory Testing of Coal and Rock

### Sample Thickness

The effect of sample thickness on the NGR rates for three different diameter plastic containers [i.e., 102-, 152-, and 190.5-mm (4.0-, 6.0-, and 7.5-in)] ID was investigated empirically in the laboratory using the ESP-2. The results are shown in figures 15 to 21. The data indicate that sample thickness of roof shale and floor fireclay obtained from two different coal seams (Pittsburgh and Coalburg) have a considerably greater influence on the NGR rates than pure coal. However, increasing the thickness of the material beyond 76 to 102 mm (3 to 4 in) caused changes in the NGR rates that were generally insignificant (tables 4 and 5).

**Table 4.—Effect of sample thickness on NGR count rate (cpm) for different container diameters**

(Pittsburgh Coal Seam)

| Sample thickness, mm | (in) | Container ID, mm (in): 70 (2.75)[1] | 102 (4) | 152 (6) | 190.5 (7.5) |
|---|---|---|---|---|---|
| **Roof shale** | | | | | |
| 0 | (0) ...... | 2,450 | 1,660 | 1,660 | 1,660 |
| 12.7 | (0.5) ..... | 2,720 | 1,850 | 2,240 | 2,200 |
| 25.4 | (1.0) ..... | 2,940 | 2,260 | 2,260 | 2,830 |
| 38.1 | (1.5) ..... | 2,970 | 2,440 | 2,540 | 3,260 |
| 63.5 | (2.5) ..... | 3,090 | 2,680 | 3,070 | 3,480 |
| 88.9 | (3.5) ..... | 3,240 | 2,820 | 3,220 | ND |
| 127.0 | (5.0) ..... | ND | ND | 3,560 | ND |
| 139.7 | (5.5) ..... | 3,440 | 2,810 | ND | ND |
| 190.5 | (7.5) ..... | 3,330 | 2,910 | ND | ND |
| 241.3 | (9.5) ..... | 3,260 | 2,980 | ND | ND |
| **Coal** | | | | | |
| 0 | (0) ...... | 2,393 | 1,630 | 1,710 | 1,600 |
| 12.7 | (0.5) ..... | 2,407 | 1,640 | 1,710 | 1,640 |
| 25.4 | (1.0) ..... | 2,487 | 1,800 | 1,860 | 1,670 |
| 76.2 | (3.0) ..... | 2,610 | 1,790 | 1,860 | 1,730 |
| 152.4 | (6.0) ..... | 2,680 | 1,790 | 1,920 | ND |
| 229.0 | (9.0) ..... | 2,670 | 1,840 | ND | ND |
| **Floor fireclay** | | | | | |
| 0 | (0) ...... | 2,040 | 1,420 | 1,510 | 1,660 |
| 12.7 | (0.5) ..... | 2,360 | 1,840 | 2,210 | 2,420 |
| 25.4 | (1.0) ..... | 2,630 | 2,090 | 2,490 | 2,550 |
| 38.1 | (1.5) ..... | 2,590 | 2,250 | 2,840 | 2,980 |
| 63.5 | (2.5) ..... | 2,730 | 2,360 | 3,070 | ND |
| 89.0 | (3.5) ..... | 2,860 | 2,560 | 3,180 | ND |
| 127.0 | (5.0) ..... | 2,980 | 2,670 | ND | ND |
| 190.5 | (7.5) ..... | 2,930 | 2,640 | ND | ND |
| 229.0 | (9.0) ..... | 2,980 | ND | ND | ND |

ND No data.

[1]NGR rates associated with the 70-mm (2.75-in) ID container are higher than the other rates because the NGR readings were taken without lead shielding; lead shielding was used for the other three diameters.

NOTE.—Samples obtained from USBM SRCM.

## Container Diameter

The effect of container diameter on the NGR rates was investigated empirically in the laboratory using the ESP-2. The results are shown in figures 15 to 21 and tables 4 and 5. The data indicate that NGR rates increase as the ID of the plastic container increases (roof shale—Pittsburgh Coal Seam). Also, the thickness of the material appears to be significant, particularly during the first 76 to 102 mm (3 to 4 in), after which the thickness does not have much effect on the NGR rates (i.e., approaching an infinitely thick layer).

**Table 5.—Effect of sample thickness on NGR count rate (cpm) for 102-mm (4-in) ID container**

(Pittsburgh and Coalburg Coal Seams)

| Sample thickness, mm | (in) | Shale[1] | Black shale[2] | Coal[1] | Gray shale[2] | Fireclay[1] | Coal[2] |
|---|---|---|---|---|---|---|---|
| 0 | (0) ... | 1,660 | 1,510 | 1,630 | 1,500 | 1,420 | 1,670 |
| 12.7 | (0.5) .. | 1,850 | 1,850 | 1,640 | 1,750 | 1,840 | 1,770 |
| 25.4 | (1.0) .. | 2,260 | 2,260 | 1,800 | 1,870 | 2,090 | 1,910 |
| 38.0 | (1.5) .. | 2,440 | 2,530 | 1,800 | 2,110 | 2,250 | 1,820 |
| 63.5 | (2.5) .. | 2,680 | 2,880 | 1,790 | 2,250 | 2,360 | 1,890 |
| 88.9 | (3.5) .. | 2,820 | 3,070 | ND | 2,370 | 2,560 | 1,920 |
| 139.7 | (5.5) .. | 2,810 | 3,120 | 1,790 | 2,490 | 2,670 | 1,930 |
| 190.5 | (7.5) .. | 2,910 | 3,090 | ND | 2,470 | 2,640 | 1,950 |
| 241.3 | (9.5) .. | 2,980 | 3,280 | 1,840 | 2,560 | ND | 2,010 |

ND No data.
[1]Pittsburgh Coal Seam.
[2]Coalburg Coal Seam.

## Airgap

Samples were also tested for NGR using the ESP-2 while increasing the distance between the detector head and the sample material in the shielded enclosure [203- by 203-mm (8- by 8-in) ID plastic container] with different sample weights. Preliminary results indicate that for rock samples, the maximum decrease in NGR readings within a distance of 25.4 mm (1 in) from the samples is 14% to 24%. Within a distance of 127 mm (5 in), the total decrease ranged from 25% to 45%. From 127- to 229-mm (5- to 9-in) distance, the decrease was in the range of 1% to 5%. Coal samples had from 3% to 5% decrease in NGR readings for a 229-mm (9-in) distance from the sample (figures 22 to 24 and tables 6 to 8) (Pittsburgh and Pocahontas Coal Seams).

**Table 6.—Effect of airgap on NGR count rates (cpm) for 203- by 203-mm (8- by 8-in) container, sample thickness 76 mm (3 in)**

(Pittsburgh Coal Seam)

| Airgap, mm | (in) | Shale | Coal | Clay |
|---|---|---|---|---|
| 0 | (0) ....... | 3,643 | 1,830 | 2,950 |
| 25.4 | (1.0) ...... | 3,107 | 1,863 | 2,987 |
| 50.8 | (2.0) ...... | 2,803 | 1,827 | 2,723 |
| 76.0 | (3.0) ...... | 2,603 | 1,860 | 2,630 |
| 127.0 | (5.0) ...... | 2,370 | 1,847 | 2,323 |
| 177.8 | (7.0) ...... | 2,233 | 1,947 | 2,210 |
| Background[1] ....... | | 1,707 | 1,707 | 1,640 |

[1]As measured in air in the middle between the floor and roof.

**Table 7. Effect of airgap on NGR count rates for coal[1]**

(Pittsburgh Coal Seam)

| Airgap, mm | (in) | NGR count rate, cpm |
|---|---|---|
| 0 | (0) ...... | 2,273 |
| 12.7 | (0.5) .... | 2,287 |
| 25.4 | (1.0) .... | 2,237 |
| 50.8 | (2.0) .... | 2,293 |
| 76.0 | (3.0) .... | 2,310 |
| 101.6 | (4.0) .... | 2,290 |
| 127.0 | (5.0) .... | 2,273 |
| 152.4 | (6.0) .... | 2,277 |
| 177.8 | (7.0) .... | 2,340 |
| 203.2 | (8.0) .... | 2,197 |

[1]Coal weight 1,040 g (2.3 lb); NGR background count rate 2,027 cpm.

**Table 8.—Effect of airgap on NGR count rates (cpm) for shale and parting**

(Pocahontas Coal Seam)

| Airgap, mm | (in) | Bottom shale, 3,680 g (8.11 lb) | Parting, 3,067 g (6.76 lb) |
|---|---|---|---|
| 0 | (0) ...... | 5,200 | 4,900 |
| 12.7 | (0.5) ..... | 4,660 | ND |
| 25.4 | (1.0) ..... | 4,327 | 3,713 |
| 50.8 | (2.0) ..... | 3,770 | 3,507 |
| 76.0 | (3.0) ..... | 3,343 | 3,197 |
| 101.6 | (4.0) ..... | 3,077 | 2,973 |
| 127.0 | (5.0) ..... | 2,917 | 2,753 |
| 152.4 | (6.0) ..... | 2,953 | 2,763 |
| 177.8 | (7.0) ..... | 2,857 | 2,697 |
| 203.2 | (8.0) ..... | 2,783 | 2,613 |
| 229.0 | (9.0) ..... | 2,647 | 2,650 |

ND No data.

Figure 22 shows the effect of distance of the NGR detector from the surface of the powdered material (60 mesh) in a 203- by 203-mm (8- by 8-in) ID plastic container, 76 mm (3 in) sample thickness. NGR rates for both roof shale and floor fireclay samples were found to decrease considerably at distances of up to 76 mm (3 in) from the sample surface. In comparison, NGR rate changes for powdered coal were found to be insignificant.

## Sample Weight

Pulverized samples from the SRCM of various weights [3,938 to 100 g (8.68 to 0.22 lb)] were tested for NGR using the ESP-2. The results indicate that the NGR readings of rock samples decreased from 37% to 58% when the sample size was reduced 90% [to 100 g (0.22 lb)]. For coal samples, the NGR reading decreased from 8% to 20% when the size was reduced 90% (figures 25 to 27, and tables 9 to 11).

**Table 9.—Effect of coal sample weight on NGR count rates—laboratory tests**

(Pittsburgh Coal Seam)

| Weight, g | (lb) | NGR count rate, cpm |
|---|---|---|
| 1,020 | (2.25) ...... | 2,200 |
| 510 | (1.12) ...... | 2,083 |
| 255 | (0.56) ...... | 2,150 |
| 127 | (0.28) ...... | 2,083 |

**Table 10.—Effect of shale, parting, and coal sample weights on NGR count rates**

(Pocahontas Coal Seam)

| Weight, g | (lb) | NGR count rate, cpm |
|---|---|---|
| Bottom shale: | | |
| 3,460 | (7.63) ... | 5,253 |
| 1,730 | (3.81) ... | 4,343 |
| 870 | (1.92) ... | 3,440 |
| 430 | (0.95) ... | 2,863 |
| 223 | (0.49) ... | 2,410 |
| 110 | (0.24) ... | 2,243 |
| Background[1] ..... | | ND |
| Bottom coal: | | |
| 2,081 | (4.59) ... | 2,667 |
| 1,040 | (2.29) ... | 2,440 |
| 520 | (1.15) ... | 2,333 |
| 260 | (0.57) ... | 2,133 |
| 130 | (1.29) ... | 2,190 |
| Background ...... | | 2,075 |
| Parting: | | |
| 3,067 | (6.76) ... | 4,953 |
| 1,533 | (3.38) ... | 3,940 |
| 767 | (1.69) ... | 3,167 |
| 383 | (0.84) ... | 2,683 |
| 192 | (0.42) ... | 2,297 |
| Background ...... | | 2,040 |

ND No data.
[1]As measured in air in the middle between the floor and roof.

## Effect of Sample Size and Thickness

To find the relationship between the NGR reading and the size and thickness of the samples, pulverized material of four samples obtained from the SRCM (Pittsburgh Coal Seam) were used. For testing, plastic containers of 70, 102, 152, and 190 mm (2.75, 4.0, 6.0, and 7.5 in) ID were used. Pulverized material was added to the containers in various thicknesses [from 13 to 241 mm (0.5 to 9.5 in)] and

NGR readings were made (figures 15 to 21 and tables 4 and 5).

**Table 11. Effect of shale and coal sample weights on NGR count rates (cpm)**

**(No. 2 Gas Coal Seam)**

| Weight, g | (lb) | NGR count rate, cpm |
|---|---|---|
| **Roof shale:** | | |
| 123 | (0.27) . . . . . | 2,170 |
| 246 | (0.54) | 2,200 |
| 492 | (1.08) : : : : : | 2,462 |
| 984 | (2.17) | 2,617 |
| 1,969 | (4.34) : : : : : | 2,890 |
| 3,938 | (8.68) . . . . . | 3,290 |
| **Coal:** | | |
| 126 | (0.28) . . . . . | 2,170 |
| 261 | (0.66) . . . . . | 2,203 |
| 602 | (1.11) . . . . . | 2,220 |
| 1,004 | (2.21) . . . . . | 2,290 |
| 2,008 | (4.43) . . . . . | 2,350 |
| Background[1] . . . . . . | | 2,076 |

[1]As measured in air in the middle between the floor and roof.

NGR readings taken of the samples from the main roof (draw slate and coal) indicate that for material 76-mm (3-in) thick in plastic containers with an ID range of 70 to 190 mm (275 to 7.50 in), the NGR reading increased above the background level from 21% to 40%.

The NGR reading of the sample from the immediate roof (shale) indicates that for 89-mm (3.50-in) material thickness and plastic container ID ranging from 70 to 190 mm (275 to 750 in), the NGR rate increased above the background level from 32% to 116%.

The NGR reading of a coal sample indicates that for material 76-mm (3-in) thick and plastic container ID ranging from 70 to 190 mm (2.75 to 7.50 in), the count rate increased above the background level from 9% to 19%.

For a floor sample (fireclay), NGR reading shows that for material 89-mm (3.5-in) thick and plastic container ID ranging from 70 to 190 mm (2.75 to 7.50 in), the NGR rate increased above the background level from 40% to 120%.

By increasing the thickness of the pulverized material in the plastic container above 76 or 89 mm (3.0 or 3.5 in), in general the NGR rate increase was found to be insignificant.

Using the same thickness of the pulverized material in l52- and 190-mm (6- and 7.5-in) ID plastic containers, the NGR reading is relatively higher than for 70- and 102-mm (2.75- and 4-in) plastic containers. For roof shale and 102-mm (4-in) plastic containers, the NGR reading ranged from 14% to 30%.

Tables 12 to 15 show the results of underground and laboratory testing analyses of samples from seven coal seams.

### Chemical Analyses

Three coal and five rock samples collected from the Bruceton mine were analyzed for ash, sulfur, and heating value. The ash content of the coal samples ranged from 5.27% to 6.29% (mean 5.80%); sulfur content ranged from 0.66% to 157% (mean 1.12%); heating value ranged from 14,053 to 14,426 Btu/lb (mean 14,258 Btu/lb) (table 15)

## KIITANNING COAL SEAM

Two visits were made to a mine in Ohio to make a series of underground NGR measurements of coal, roof, and floor to determine if a sufficient NGR difference existed between the coal and adjacent strata. Coal and rock samples were also collected for laboratory analyses. This particular mine operates in the Middle Kittanning Coal Seam. The seam thickness ranges from 1,067 to 1,422 mm (42 to 56 in) with a mean thickness of 1,321 mm (52 in). The immediate roof is composed primarily of laminated hard draw slate. Two or more rock partings, 51 to 76-mm (2- to 3-in) thick, are typically found in the coal 406 to 508 mm (16 to 20 in) below the roof. The immediate floor strata are composed of relatively soft-to-hard fireclay.

### Underground Testing

During the first visit, NGR readings were made at four different locations in the mine using the ESP-2. A total of 21 coal and rock samples were collected for laboratory testing. NGR readings during the second visit were made at eight points in the vicinity of the third location. A total of 22 samples were collected during the second visit. The results of the underground and laboratory tests are summarized in tables 12 to 14.

Computed NGR ratios associated with the first visit are as follows: underground roof-to-top coal (R:TC) ratio for four locations ranged from 1.21 to 1.33 (mean 1.26); floor-to-bottom coal (F:BC) ratio ranged from 1.60 to 236 (mean 2.03).

Underground tests during the second visit were made with the RHC 801 and the GRS-500 at six locations, and with the ESP-2 at eight locations. Slots were made in the coal ribs at six of these locations leaving from 38 to 559 mm (1.5 to 22 in) of roof coal above each slot. Table 14 lists RHC 801 and ESP-2 readings as the roof coal thickness varied and the position of the RHC 801 was changed at these locations (ii the coal cut, outside the coal at the same level, and near the immediate roof). The RHC 801 data also showed that the airgap has little influence on NGR readings of the immediate roof [about 8% difference for up to 330 mm (13 in) of airgap].

Table 12.—Comparison of NGR count rates for different coal seams—underground tests

| Coal seam | Count rate, cpm | | | Ratios to coal | NGR sensor | | |
|---|---|---|---|---|---|---|---|
| | ESP-2 | RHC801 | GRS-500 | | ESP-2 | RHC801 | GRS-500 |
| Pittsburgh: | | | | | | | |
| Roof | 10,160 | 11,448 | 16,086 | R:C | 2.59 | 2.16 | ND |
| Coal | 3,920 | 5,300 | ND | NAp | NAp | NAp | NAp |
| Floor | 7,900 | 13,510 | ND | F:C | 2.01 | 2.36 | ND |
| Background[1] | 6,600 | 7,530 | ND | NAp | NAp | NAp | NAp |
| Kittanning: | | | | | | | |
| Roof | 12,461 | 18,480 | 27,456 | R:C | 1.41 | 1.58 | 1.24 |
| Coal | 8,856 | 11,687 | 22,162 | NAp | NAp | NAp | NAp |
| Floor | 12,845 | ND | 26,508 | F:C | 1.45 | ND | 1.20 |
| Partings | 9,337 | ND | ND | P:C | 1.05 | ND | ND |
| Background | 11,359 | ND | 25,740 | NAp | NAp | NAp | NAp |
| Freeport: | | | | | | | |
| Roof | 10,802 | ND | 25,545 | R:C | 1.64 | ND | 1.16 |
| Coal | 6,575 | ND | 22,050 | NAp | NAp | NAp | NAp |
| Floor | 12,733 | ND | 41,484 | F:C | 1.94 | ND | 1.88 |
| Partings | 9,097 | ND | 24,305 | P:C | 1.38 | ND | 1.10 |
| Background | 8,686 | ND | 31,848 | NAp | NAp | NAp | NAp |
| Clarion:[2] | | | | | | | |
| Roof | 5,044 | ND | ND | R:C | 1.57 | ND | ND |
| Coal | 3,216 | ND | ND | NAp | NAp | NAp | NAp |
| Floor | 6,913 | ND | ND | F:C | 2.15 | ND | ND |
| Partings | 3,606 | ND | ND | P:C | 1.12 | ND | ND |
| Background | 5,342 | ND | ND | NAp | NAp | NAp | NAp |
| Illinois No. 5: | | | | | | | |
| Roof | 20,880 | ND | ND | R:C | 3.08 | ND | ND |
| Coal | 6,790 | ND | ND | NAp | NAp | NAp | NAp |
| Floor | 12,400 | ND | ND | F:C | 1.83 | ND | ND |
| Background | 14,650 | ND | ND | NAp | NAp | NAp | NAp |
| Hiawatha: | | | | | | | |
| Roof | 6,337 | ND | ND | R:C | 2.70 | ND | ND |
| Coal | 2,345 | ND | ND | NAp | NAp | NAp | NAp |
| Floor | 5,595 | ND | ND | F:C | 2.39 | ND | ND |
| Partings | 4,844 | ND | ND | P:C | 2.07 | ND | ND |
| Background | 3,564 | ND | ND | NAp | NAp | NAp | NAp |
| Wadge: | | | | | | | |
| Roof | 9,588 | ND | ND | R:C | 2.25 | ND | ND |
| Coal | 4,256 | ND | ND | NAp | NAp | NAp | NAp |
| Floor | 6,331 | ND | ND | F:C | 1.49 | ND | ND |
| Background | 6,320 | ND | ND | NAp | NAp | NAp | NAp |

NAp Not applicable.
ND No data.
[1]As measured in air in the middle between the floor and roof.
[2]PHA without shield.

For ESP-2, computed ratios associated with the second visit were R:TC ratio ranged from 1.06 to 1.55 (mean 1.37) and F:BC ratio ranged from 1.65 to 1.74 (mean 1.69). For the GRS-500, R:C ratio was 1.24 and F:C ratio was 1.20.

## Laboratory Testing

A total of 43 coal and rock samples collected during the two visits were tested in the laboratory using the ESP-2. Laboratory tests of 21 samples collected during the first visit indicate that the R:TC ratio ranged from 1.40 to 1.69 (mean 1.55) and the F:BC ratio ranged from 1.83 to 2.27 (mean 1.98). The mean NGR readings for 11 roof samples were 2,864 cpm; 14 top coal samples, 1,914 cpm; 5 bottom coal samples, 1,572 cpm; 11 floor samples, 3,040 cpm; and 2 partings, 2,063 cpm. The mean R:TC was 1.50 and the mean F:BC was 1.93. Using the GRS-500, R:C ratio was 1.47 and F:C ratio was 1.55.

KUT radiometric analysis of one roof sample indicates that the bulk density was 1.77 g/cc, RaeU[5] was 4.71 ppm, thorium (Th) was 18.10 ppm, and potassium (K-40) was 3.31%. For one coal sample, bulk density was 0.94 g/cc, RaeU was 0.689 ppm, Th was 2.48 ppm, and K-40 was 0.17%. One floor sample had a bulk density of 1.58 g/cc, RaeU of 5.33 ppm, Th of 19.20 ppm, and K-40 of 3.64%

[5]RaeU is the amount of uranium, under conditions of secular equilibrium, required to support the measured amount of radium daughters.

Table 13.—Comparison of NGR count rates for different coal seams—laboratory tests

| Coal seam | Count rate, cpm | | | Ratios to coal | NGR sensor | | |
|---|---|---|---|---|---|---|---|
| | ESP-2 | RHC801 | GRS-500 | | ESP-2 | RHC801 | GRS-500 |
| Pittsburgh: | | | | | | | |
| Roof | 2,446 | 5,754 | 2,518 | R:C | 1.58 | 1.18 | 1.20 |
| Coal | 1,545 | 4,887 | 2,087 | NAp | NAp | NAp | NAp |
| Floor | 2,110 | 5,718 | 3,258 | F:C | 1.37 | 1.18 | 1.56 |
| Background | 1,442 | 3,336 | ND | NAp | NAp | NAp | NAp |
| Kittanning: | | | | | | | |
| Roof | 2,970 | 5,010 | 3,546 | R:C | 1.63 | 1.14 | 1.47 |
| Coal | 1,825 | 4,396 | 2,409 | NAp | NAp | NAp | NAp |
| Floor | 3,284 | 5,055 | 3,726 | F:C | 1.80 | 1.15 | 1.55 |
| Partings | 2,064 | ND | ND | P:C | 1.13 | ND | ND |
| Background | 1,526 | 3,642 | 1,926 | NAp | NAp | NAp | NAp |
| Freeport: | | | | | | | |
| Roof | 3,173 | 3,300 | 3,552 | R:C | 1.65 | 1.05 | 1.22 |
| Coal | 1,923 | 3,137 | 2,905 | NAp | NAp | NAp | NAp |
| Floor | 3,318 | 4,010 | 8,768 | F:C | 1.73 | 1.28 | 3.02 |
| Partings | 3,330 | 3,113 | 3,840 | P:C | 1.73 | 1.00 | 1.32 |
| Background | 1,517 | 2,823 | 1,950 | NAp | NAp | NAp | NAp |
| Clarion: | | | | | | | |
| Roof | 2,444 | 5,004 | 3,898 | R:C | 1.45 | 1.15 | 1.73 |
| Coal | 1,683 | 4,340 | 2,252 | NAp | NAp | NAp | NAp |
| Floor | 3,224 | 5,694 | 3,948 | F:C | 1.92 | 1.31 | 1.75 |
| Partings | 2,433 | 4,570 | 2,943 | P:C | 1.45 | 1.05 | 1.30 |
| Background | 1,521 | 3,438 | ND | NAp | NAp | NAp | NAp |
| Illinois No. 5: | | | | | | | |
| Roof | 3,748 | 4,470 | 4,104 | R:C | 1.97 | 1.12 | 1.64 |
| Coal | 1,905 | 3,984 | 2,496 | NAp | NAp | NAp | NAp |
| Floor | 2,664 | 4,110 | 3,341 | F:C | 1.40 | 1.03 | 1.34 |
| Background | 1,482 | 2,646 | 1,902 | NAp | NAp | NAp | NAp |
| Hiawatha: | | | | | | | |
| Roof | 2,568 | 4,776 | 3,444 | R:C | 1.68 | 1.16 | 1.53 |
| Coal | 1,532 | 4,101 | 2,254 | NAp | NAp | NAp | NAp |
| Floor | 2,012 | 4,595 | 2,975 | F:C | 1.31 | 1.12 | 1.32 |
| Partings | 1,982 | 3,960 | 2,280 | P:C | 1.29 | 1.13 | 1.01 |
| Background | ND | ND | ND | NAp | NAp | NAp | NAp |
| Wadge: | | | | | | | |
| Roof | 3,917 | 4,912 | 3,288 | R:C | 1.60 | 1.10 | 1.48 |
| Coal | 2,454 | 4,463 | 2,220 | NAp | NAp | NAp | NAp |
| Floor | ND | ND | 3,504 | F:C | ND | ND | 1.58 |
| Background | 2,418 | 3,594 | ND | NAp | NAp | NAp | NAp |

NAp Not applicable.
ND No data.

Table 14.—Comparison of RHC 801 and ESP-2 NGR count rates (cpm) for Kittanning Coal Seam—underground tests

| Location | Coal thickness, | | RHC 801 | | | ESP-2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | mm | (in) | Inside coal slot | Outside coal slot | Immed. roof | Roof coal | Immed. roof | Immed. floor | Floor coal |
| 1 | 63.5 | (2.5) | 12,060 | ND | ND | ND | 11,333 | 11,033 | ND |
| 1 | 152.4 | (6.0) | 11,460 | 17,340 | 18,300 | 8,693 | 11,333 | ND | ND |
| 1 | 330.2 | (13.0) | 11,520 | 16,680 | ND | ND | 11,333 | ND | ND |
| 2 | 343.0 | (13.5) | 10,080 | 16,800 | 19,200 | 8,340 | 12,933 | 12,100 | ND |
| 3 | 406.4 | (16.0) | 9,960 | 17,280 | 18,960 | 6,860 | ND | ND | ND |
| 4 | 38.1 | (1.5) | 15,360 | 17,460 | 18,180 | 12,000 | 12,667 | 13,433 | ND |
| 4 | 88.9 | (3.5) | 14,520 | ND | ND | ND | ND | ND | ND |
| 5 | 482.6 | (19.0) | 10,920 | 16,800 | 17,640 | ND | 11,700 | 11,967 | 6,957 |
| 6 | 558.8 | (22.0) | 9,300 | 17,340 | 18,600 | ND | 11,733 | 11,733 | 8,043 |
| 7 | 0 | (0) | ND | ND | ND | 10,567 | 12,433 | 12,267 | 7,063 |
| 8 | 0 | (0) | ND | ND | ND | 10,867 | 13,700 | 15,833 | 9,613 |

ND No data.

**Table 15.—Laboratory analyses of roof, coal, floor, and parting samples for different coal seams**

| Coal seam and number of mines | No. of samples | Chemical analyses: Ash content, % | | Sulfur content, % | | Heating value, Btu/lb | | No. of samples | NGR: Gamma ray, cpm | | Ratio to coal |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD | | Mean | SD | |
| Pittsburgh (1): | | | | | | | | | | | |
| Roof ......... | 3 | 76.2 | 19.24 | 0.56 | 0.69 | 2,550 | 3,106 | 7 | 2,446 | 700 | 1.58 |
| Coal ......... | 3 | 5.8 | 0.50 | 1.12 | 0.45 | 14,258 | 189 | 6 | 1,545 | 23 | NAp |
| Floor ......... | 2 | 85.9 | 0.22 | 1.68 | 0.20 | 934 | 245 | 4 | 2,110 | 406 | 1.37 |
| Kittanning (1): | | | | | | | | | | | |
| Roof ......... | 5 | 88.6 | 4.15 | 3.24 | 2.53 | 655 | 511 | 11 | 2,970 | 198 | 1.63 |
| Coal ......... | 10 | 21.3 | 9.34 | 2.91 | 1.04 | 11,083 | 1,531 | 19 | 1,825 | 251 | NAp |
| Floor ......... | 5 | 93.6 | 1.38 | 0.45 | 0.21 | 82 | 124 | 11 | 3,284 | 398 | 1.80 |
| Parting ....... | ND | ND | ND | ND | ND | ND | ND | 1 | 2,064 | 0 | ND |
| Freeport (2): | | | | | | | | | | | |
| Roof ......... | 4 | 86.1 | 12.20 | 0.52 | 0.67 | 1,174 | 1,949 | 8 | 3,173 | 433 | 1.65 |
| Coal ......... | 13 | 13.7 | 7.65 | 3.34 | 5.61 | 13,354 | 1,437 | 28 | 1,923 | 250 | NAp |
| Floor ......... | 5 | 88.8 | 5.74 | 3.03 | 1.76 | 668 | 943 | 13 | 3,318 | 483 | 1.73 |
| Parting ....... | 2 | 81.4 | 6.20 | 0.53 | 0.61 | 1,493 | 1,209 | 2 | 3,330 | 339 | 1.73 |
| Clarion (1): | | | | | | | | | | | |
| Roof ......... | 4 | 45.1 | 14.92 | 14.8 | 3.89 | 6,654 | 1,053 | 13 | 2,718 | 615 | 1.60 |
| Coal ......... | 7 | 10.2 | 11.42 | 4.33 | 3.84 | 12,665 | 1,762 | 9 | 1,700 | 170 | NAp |
| Floor ......... | 2 | 90.0 | 0.89 | 0.48 | 0.54 | 166 | 0 | 6 | 3,330 | 1,025 | 1.96 |
| Parting ....... | 4 | 83.7 | 3.92 | 2.31 | 1.82 | 1,264 | 428 | 1 | 2,207 | 0 | 1.30 |
| Illinois No. 5 (1): | | | | | | | | | | | |
| Roof .......... | 2 | 85.4 | 13.27 | 1.06 | 0.38 | 1,580 | 2,200 | 5 | 3,748 | 749 | 1.97 |
| Coal .......... | 3 | 12.0 | 7.63 | 2.74 | 1.19 | 12,552 | 546 | 7 | 1,905 | 461 | NAp |
| Floor .......... | 1 | 92.8 | 0 | 5.45 | 0 | 457 | 0 | 5 | 2,664 | 576 | 1.40 |
| Parting ......... | ND | ND | ND | ND | ND | ND | ND | 1 | 4,647 | 0 | 2.44 |
| Hiawatha (1): | | | | | | | | | | | |
| Roof .......... | | 75.4 | 3.53 | 0.47 | 0.26 | 2,113 | 950 | 7 | 2,568 | 395 | 1.68 |
| Coal .......... | 6 | 8.4 | 3.54 | 0.59 | 0.26 | 13,260 | 588 | 7 | 1,532 | 112 | NAp |
| Floor .......... | 4 | 65.6 | 18.30 | 1.19 | 1.34 | 4,472 | 2,688 | 6 | 2,012 | 363 | 1.31 |
| Parting ......... | 1 | 51.0 | 0 | 0.14 | 0 | 6,783 | 0 | 5 | 1,982 | 257 | 1.29 |
| Wadge (1): | | | | | | | | | | | |
| Roof .......... | 5 | 91.5 | 0.57 | 1.30 | 0.44 | 524 | 130 | 5 | 3,917 | 645 | 1.606 |
| Coal .......... | 7 | 6.4 | 2.79 | 0.54 | 0.40 | 13,030 | 440 | 7 | 2,454 | 302 | NAp |
| Parting ......... | 1 | 49.1 | 0 | 0.27 | 0 | 6,611 | 0 | 1 | 3,740 | 0 | 1.52 |

SD Standard deviation.
NAp Not applicable.
ND No data.

(tables 16 to 18). No NGR testing of these samples were made because they were too small.

Ten coal and ten rock samples were chemically analyzed for ash, sulfur, and heating value. The chemical analyses of four samples of the top coal and two samples of the bottom coal indicate that the ash content of the top coal ranged from 18.46% to 32.72% (mean 27.53%); sulfur content ranged from 2.15% to 3.35% (mean 2.87%); heating value ranged from 9,340 to 11,510 Btu/lb (mean 10,190 Btu/lb). For the bottom coal, the ash content ranged from 7.90% to 8.37% (mean 8.14%); sulfur content ranged from 2.07% to 5.19% (mean 3.63%); and the mean heating value was 13,160 Btu/lb. Mean ash content of 10 coal samples was 21.30%, mean sulfur content 2.91%, and mean heating value 11,083 Btu/lb (table 15).

## FREEPORT COAL SEAM

The Upper Freeport Coal Seam in the study area had a mean thickness of 2,286 mm (90 in) and ranged from 1,829 to 2,743 mm (72 to 108 in). One or two rock partings, from 51 to 914 mm (2 to 36 in) thick, are found in the middle of the seam. The immediate roof strata in the sampled areas are hard, dark gray, laminated shale up to 2.44 m (8 ft) thick. The immediate floor strata are hard, water-sensitive, gray shale, occasionally mixed with coal.

### Underground Testing

Underground NGR measurements were conducted in two mines in the Upper Freeport Coal Seam in West

**Table 16.—KUT[1] radiometric and chemical laboratory analyses of roof samples**

| Seam (State) | Radiometric analysis | | | | | | Chemical analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sample No. | Bulk Density, g/cc | RaeU,[2] ppm | Thorium, ppm | Potassium, % | NGR,[3] cpm | Sample No. | Ash, % | Sulfur, % | Heating value, BTU/lb |
| B seam (CO) | 1 | 1.71 | 3.97 | 16.70 | 2.70 | 2,133 | NA | NA | NA | NA |
| Maxwell (CO) | 1 | 1.30 | 7.11 | 19.20 | 1.56 | 2,167 | NA | NA | NA | NA |
| No. 5 (IL) | 2 | 1.28 | 25.40 | 25.10 | 0.30 | 3,287 | 2 | 94.73 | 0.79 | 25 |
| No. 6 (IL) | 1 | 1.33 | 35.80 | 9.50 | 2.82 | 2,863 | 1 | 73.94 | 2.09 | 3,337 |
| Hazard (KY) | 1 | 1.43 | 14.42 | 15.80 | 4.35 | 2,133 | NA | NA | NA | NA |
| No. 9 (KY) | 1 | 1.14 | [4]148.00 | 5.70 | 1.80 | NA | 1 | 72.92 | 2.79 | 3,597 |
| No. 11 (KY) | 4 | 1.45 | 3.34 | 15.60 | 3.09 | 2,003 | NA | NA | NA | NA |
| Upper Left Fork (NM) | 1 | 1.62 | 5.81 | 18.50 | 2.22 | 2,338 | NA | NA | NA | NA |
| Clarion (OH) | 3(B) | 1.20 | 3.31 | 14.80 | 2.24 | 1,493 | NA | NA | NA | NA |
| | 4 | 1.33 | 3.14 | 13.60 | 1.60 | 1,620 | | | | |
| Kittanning (OH) | 4 | 1.77 | 4.71 | 18.10 | 3.31 | ([5]) | 4 | 87.01 | 6.34 | 766 |
| Pittsburgh (PA) | 1(A) | 1.61 | 4.83 | 19.40 | 1.90 | 1,453 | 1(A) | 89.70 | 0.62 | 490 |
| | 1(B) | 1.64 | 5.38 | 19.50 | 1.57 | 1,550 | 1(B) | 90.25 | 0.33 | 272 |
| Hiawatha (UT) | 1 | 1.76 | 3.50 | 8.08 | 1.59 | 1,517 | 1 | 79.06 | 0.59 | 2,216 |
| Coalburg (WV) | 1 | 1.64 | 4.13 | 14.40 | 2.80 | 2,023 | 1 | 91.78 | 0.20 | 473 |
| Freeport (WV) | 5 | 1.50 | 4.74 | 18.10 | 2.32 | 2,143 | 5 | 91.11 | 0.35 | 354 |
| No. 38 (WY) | 2 | 1.43 | 4.97 | 12.80 | 1.76 | 1,240 | NA | NA | NA | NA |
| Mean | NAp | 1.48 | 8.41 | 15.58 | 2.23 | 1,998 | NAp | NAp | NAp | NAp |

NA Not available.
NAp Not applicable.
[1]KUT = *potassium/uranium/thorium.*
[2]RaeU is the amount of uranium, under conditions of secular equilibrium, that would be required to support the measured amount of radium daughters.
[3]ESP-2 unit used for lab testing.
[4]*Not included in mean value because results are 17.6 times higher than mean value.*
[5]Sample too small to measure.

Virginia using the RHC 801, the ESP-2, and the GRS-500. The results indicate relatively large variations in the NGR readings at different sections in the mines. NGR readings were made at five locations at each mine and a total of 46 coal and rock samples were collected for laboratory analyses.

Underground NGR tests were made primarily with the ESP-2. The immediate roof strata at the first mine could not be measured (except at one location) because of the height of the roof. When using the ESP-2, R:C for both mines was 1.64 and F:C was 1.94. The parting-to-coal (P:C) ratio was 1.38. When using the GRS-500, R:C was 1.16, F:C was 1.88, and P:C was 1.10 (table 12).

During a visit to a second mine, the RHC 801 unit was installed on a new Joy 6LS longwall shearer and was calibrated to leave about 76 mm (3 in) of coal on the roof to protect weak roof strata. The unit used two indicators, one of which was used by the operator for remote control. USBM personnel followed the shearer along the 213.4-m (700-ft) longwall face. In general, the RHC 801 indicator lights were on the proper horizon line. Occasionally, one yellow light appeared, indicating thickening of the coal. At one point there was a minor roof cave-in during mining and a red light appeared on both indicators, which indicated that the roof coal was thinner than required, no coal was left on the roof, or more NGR was present in the roof rock. Longwall operators stated that the RHC unit operated satisfactorily for over four weeks without any major problems and appeared to work well under adverse mining conditions.

## Laboratory Testing

Fifty-one coal and rock samples were tested in the laboratory for NGR using ESP-2 and GRS-500. For the ESP-2, the mean R:C ratio was 1.65, and F:C and P:C ratios were each 1.73. For the GRS-500, the R:C ratio was 1.22, F:C was 3.02, and P:C was 1.32 (table 13).

KUT radiometric analysis of one roof sample indicates that the bulk density was 1.50 g/cc, RaeU was 4.74 ppm, Th was 18.10 ppm, and K-40 was 2.32%. For one coal sample, bulk density was 1.04 g/cc, RaeU was 1.42 ppm, Th was 3.21 ppm, and K-40 was 0.39%. One floor sample had bulk density of 1.71 g/cc, RaeU of 7.08 ppm, Th of 13.50 ppm, and K-40 of 1.79%. Laboratory testing of these samples indicate that for roof, NGR was 2,143 cpm, for coal it was 1,317 cpm, and for floor it was 2,040 cpm (tables 16 to 18).

Thirteen coal and eleven rock samples were analyzed for ash, sulfur, and heating value. The ash content of the 13 coal samples ranged from 5.77% to 29.35% (mean 13.70%); the sulfur content ranged from 0.63% to 21.50%

Table 17.—KUT[1] radiometric and chemical laboratory analyses of coal samples

| Seam (State) | Radiometric analysis | | | | | | Chemical analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sample No. | Bulk density, g/cc | RaeU,[2] ppm | Thorium, ppm | Potassium, % | NGR,[3] cpm | Sample No. | Ash, % | Sulfur, % | Heating value, Btu/lb |
| B seam (CO) ...... | 4 | 0.91 | 0.35 | 0.77 | <0.10 | 1,190 | NA | NA | NA | NA |
| Maxwell (CO) ...... | 2 | 0.88 | 1.25 | 3.33 | <0.10 | 1,273 | NA | NA | NA | NA |
| Wadge (CO) ....... | 1 | 0.92 | 0.39 | 0.95 | <0.10 | 1,213 | 3 | 4.20 | 0.38 | 13,427 |
| Hazard (KY) ....... | 6 | 0.92 | 0.33 | 0.70 | <0.10 | 1,223 | NA | NA | NA | NA |
| No. 9 (KY) ........ | 4 | 0.99 | 1.31 | 2.57 | 0.43 | 1,210 | 3 | 13.42 | 4.34 | 12,414 |
| No. 11 (KY) ....... | 6 | 0.93 | 3.50 | 0.96 | 0.13 | 1,220 | 6 | 7.41 | 3.09 | 13,354 |
| Upper Left Fork (NM) | 2 | 0.89 | 0.66 | 1.78 | <0.10 | 1,173 | NA | NA | NA | NA |
| Clarion (OH) ...... | 5 | 0.89 | 0.36 | 0.74 | <0.10 | 1,197 | NA | NA | NA | NA |
| Kittanning OH) ..... | 5 | 0.94 | 0.68 | 2.48 | 0.17 | ([4]) | 5 | 12.88 | 3.03 | 12,434 |
| Pittsburgh (PA) ..... | 2 | 0.93 | 0.50 | 0.80 | <0.10 | 1,100 | 2 | 5.50 | 2.51 | 14,421 |
| | 3 | 1.04 | 1.43 | 4.61 | 0.32 | 1,240 | 3 | 3.87 | 1.12 | 14,517 |
| Hiawatha (UT) ..... | 2 | 0.89 | 0.67 | 3.25 | <0.10 | 1,113 | 2 | 13.26 | 0.46 | 12,461 |
| | | | | | | | 3 | 4.84 | 0.63 | 13,825 |
| Coalburg (WV) ..... | 4 | [5]1.48 | [5]3.42 | [5]15.70 | [5]2.16 | [5]1,740 | 2 | 21.31 | 0.43 | 11,601 |
| Freeport (WV) ...... | 5 | 1.04 | 1.42 | 3.21 | 0.39 | 1,317 | 2 | 8.91 | 1.95 | 14,230 |
| No. 38 (WY) ....... | 1 | 0.89 | 0.66 | 1.03 | <0.10 | 1,183 | NA | NA | NA | NA |
| | 2 | 0.92 | 1.39 | 1.22 | <0.10 | 1,240 | | | | |
| Mean .......... | NAp | 0.93 | 0.99 | 1.90 | [6]0.29 | 1,207 | NAp | NAp | NAp | NAp |

NA Not available.
NAp Not applicable.
[1]KUT = potassium/uranium/thorium.
[2]RaeU is the amount of uranium, under conditions of secular equilibrium, that would be required to support the measured amount of radium daughters.
[3]ESP-1 unit used for lab testing.
[4]Sample too small to measure.
[5]Not included in mean value because results are much higher in the high ash coal.
[6]Only the five samples above 0.1 were included in mean value.

(mean 3.34%); and the heating value ranged from 10,021 to 14,829 Btu/lb (mean 13,354 Btu/lb) (table 15).

## CLARION COAL SEAM

A visit was made to a mine operating in the Clarion Coal Seam in Ohio. The immediate roof of the Clarion Coal Seam is hard limestone, up to 0.91 m (3 ft) thick, followed by sandy shale and sandstone. The mean coal seam thickness in this particular mine is 1.448 mm (57 in) and ranges from 1,219 to 1,676 mm (48 to 66 in). Two rock partings, 51 mm and 152 to 178 mm (2 in and 6 to 7 in) thick, are found at different distances below the coal roof. To obtain the required entry height for the continuous mining machine, from 203 to 305 mm (8 to 12 in) of the floor fireclay must be removed during mining.

### Underground Testing

Underground NGR readings were made at five different locations using the ESP-2, with a single-channel pulse height analyzer (PHA) option without the lead shield. The results indicated relatively large variations in the NGR rates underground. For the immediate roof (limestone and sandstone), the mean value was 5,044 cpm; for coal, the mean value was 3,216 cpm; for floor (fireclay), the mean value was 6,913 cpm; and for rock partings, the mean value was 3,606 cpm. The mean value for the underground ambient air measured at the center of the cross-sections was 4,800 cpm, which is similar to the mean value of the roof, coal, floor, and rock partings combined (4,695 cpm). The mean R:C ratio was 1.57 and mean F:C ratio was 2.15. For limestone roof, R:C ratio was 1.20, and for sandstone roof, R:C was 2.00. The P:C ranged from 0.90 to 1.33 (mean 1.12). Higher ambient air readings were noticed at one location where the floor strata are composed of shale and/or draw slate with high NGR readings (table 12).

### Laboratory Testing

Laboratory tests of coal and rock samples collected at five locations underground showed similar trends in NGR readings. When using the ESP-2, the mean R:C ratio was 1.45, the mean F:C ratio was 1.92, and the P:C was 1.45. For the limestone roof, R:C ranged from 1.40 to 1.70, and for the shale-draw slate floor, F:C ranged from 1.85 to 2.40. When using the GRS-500, the R:C ratio was 1.73, the F:C ratio was 1.75, and the P:C was 1.30 (table 13).

KUT radiometric analysis of one sample of roof and one rock parting indicates that the bulk density was 1.20 and 1.33 g/cc, RaeU was 3.31 and 3.14 ppm, Th was 14.80

Table 18.—KUT[1] radiometric and chemical laboratory analyses of floor samples

| Seam (State) | Radiometric analysis | | | | | | Chemical analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sample No. | Bulk Density, g/cc | RaeU,[2] ppm | Thorium, ppm | Potassium, % | NGR,[3] cpm | Sample No. | Ash, % | Sulfur, % | Heating value, Btu/lb |
| Wadge (CO) | 2 | 1.21 | 5.44 | 13.70 | 2.28 | 1,730 | NA | NA | NA | NA |
| No. 5 (IL) | 1 | 1.68 | 13.00 | 27.50 | 1.32 | 3,080 | 1 | 76.01 | 1.33 | 3,135 |
| No. 6 (IL) | 2 | 1.54 | 2.47 | 15.00 | 2.22 | 1,573 | 2 | 94.76 | 0.65 | 19 |
| Hazard (KY) | 7 | 1.71 | 6.91 | 56.60 | 0.18 | 2,313 | NA | NA | NA | NA |
| No. 9 (KY) | 6 | 1.54 | 3.67 | 14.60 | 3.40 | 1,607 | 5 | 94.52 | 1.13 | 5 |
| Upper Left Fork (NM) | 4 | 0.80 | 0.90 | 2.53 | <0.10 | 1,230 | NA | NA | NA | NA |
| Kittanning (OH) | 8 | 1.58 | 5.33 | 19.20 | 3.64 | ([4]) | 8 | 34.06 | 1.23 | 9,132 |
| Pittsburgh (PA) | 5 | 1.72 | 3.10 | 15.20 | 2.07 | 1,433 | 5 | 91.57 | 0.57 | 169 |
| | 8 | 1.50 | 7.18 | 14.60 | 1.67 | 1,667 | 8 | 93.73 | 2.18 | 155 |
| Hiawatha (UT) | 4 | 1.20 | 3.87 | 6.36 | 0.54 | NA | 4 | 66.26 | 1.40 | 4,534 |
| Coalburg (WV) | 5 | 1.40 | 3.87 | 15.80 | 3.20 | 1,687 | 5 | 91.91 | 0.06 | 205 |
| Freeport (WV) | 2 | 1.71 | 7.08 | 13.50 | 1.79 | 2,040 | 4 | 79.23 | 1.40 | 2,289 |
| Mean | NAp | 1.47 | 5.24 | 17.88 | 2.03 | 1,836 | NAp | NAp | NAp | NAp |

NA Not available.
NAp Not applicable.
[1]KUT = potassium/uranium/thorium.
[2]RaeU is the amount of uranium, under conditions of secular equilibrium, that would be required to support the measured amount of radium daughters.
[3]ESP-2 unit used for lab testing.
[4]Sample too small to measure.

and 13.60 ppm, and K-40 was 2.24% and 1.60%. One coal sample had bulk density of 0.89 g/cc, RaeU of 0.36 ppm, Th of 0.74 ppm, and K-40 of <0.10%. Floor samples were not available for KUT testing. Laboratory testing indicates that roof and parting samples have NGR of 1,493 and 1,620 cpm, and coal sample has 1,197 cpm (tables 16, 17).

Seven coal and ten rock samples were analyzed for ash, sulfur, and heating value. The results of the coal samples indicate that the ash content ranged from 3.68% to 35.51% (mean 10.20%); sulfur content ranged from 2.08% to 12.92% (mean 4.33%); and heating value ranged from 8,780 to 13,810 Btu/lb (mean 12,665 Btu/lb) (table 15).

## ILLINOIS NO. 5 COAL SEAM

A visit was made to a mine operating in the No. 5 Coal Seam in Illinois. Seam thickness in this mine ranges from 1,270 to 1,829 mm (50 to 72 in), with a mean value of 1,676 mm (66 in). The immediate roof is laminated, thin, hard black shale with limestone nodules and clay veins up to 2,438 mm (96 in) thick. A lot of clay veins are also found in coal. The immediate floor is soft to relatively hard underclay, which is normally dry but water-sensitive. Limestone is generally found beneath the underclay.

### Underground Testing

NGR data were obtained at seven locations near the active mining operations. Underground measurements indicated relatively small variations in the NGR readings at different sections as well as in the same entry (left or right rib). For the black roof shale, NGR readings were found to vary from 18,230 to 24,630 cpm, with a mean value of 20,880 cpm. For coal, NGR readings ranged from 5,640 cpm in the western section to 7,900 cpm in the eastern section, with a mean value of 6,790 cpm. For floor underclay, NGR readings ranged from 11,030 cpm in the southern section to 13,700 cpm in the eastern section, with a mean value of 12,400 cpm. One reading taken on a clay vein was 9,100 cpm and a reading taken on a limestone nodule was 8,200 cpm. The mean NGR reading of the ambient air in the center of the entry cross-section was 14,650 cpm, and ranged from 13,130 to 15,650 cpm, which is only about 9% lower than the mean value of the NGR readings of roof, floor, and coal combined. The R:C ratio varied from location to location and ranged from 2.47 to 3.72, with a mean value of 3.08. The F:C ratio ranged from 1.52 to 2.07, with a mean value of 1.83 (table 12).

### Laboratory Testing

Laboratory tests of 13 coal and rock samples collected in this mine at four locations showed similar variations in NGR readings. When using the ESP-2, NGR mean value of five black shale roof samples was 3,748 cpm; for seven coal samples the mean value was 1,905 cpm; for five floor samples the mean value was 2,664 cpm; and for one rock parting, it was 4,647 cpm. The mean R:C ratio was 1.97, and the mean F:C ratio was 1.40 (table 13).

Laboratory testing of six other coal and rock samples obtained earlier from the same mine had a R:C ratio of 3.17 and a F:C ratio of 1.34. When using the GRS-500, the R:C was 1.64, the F:C was 1.34, and the P:C was 1.39.

KUT radiometric analysis of one roof sample indicates that the bulk density was 1.28 g/cc, RaeU was 25.40 ppm, Th was 25.10 ppm, and K-40 was 0.30%. For one floor sample, the bulk density was 1.68 g/cc, RaeU was 13.00 ppm, Th was 27.50 ppm, and K-48 was 1.32%. No coal sample was available for testing. NGR laboratory testing of these samples showed that the roof sample has 3,287 cpm and the floor sample has 3,080 cpm (tables 16, 18).

Three coal and three rock samples were analyzed for ash, sulfur, and heating value. Ash content of three coal samples ranged from 7.86% to 15.73% (mean 12.00%); sulfur content ranged from 1.69% to 4.03% (mean 2.74%); and heating value ranged from 12,069 to l3,144 Btu/lb (mean 12,552 Btu/lb) (table 15)

## HIAWATHA COAL SEAM

A visit was made to a mine operating in the Hiawatha Coal Seam in Utah. The immediate roof was gray to black relatively soft shale, which was occasionally mixed with coal and sandstone. The seam thickness ranged from 1,829 to 2,438 mm (72 to 96 in), with a mean value of 2,286 mm (90 in). In general, one rock parting of variable thickness was found in the coal seam. The immediate floor was soft fireclay or shale, occasionally mixed with sandstone.

### Underground Testing

NGR readings using the ESP-2 were made at six underground locations and a total of 19 coal and rock samples were collected. For roof shale, the NGR readings ranged from 4,433 to 8,663 cpm, with a mean value of 6,337 cpm. The NGR readings for coal ranged from 1,323 to 3,663 cpm, with a mean value of 2,345 cpm. For floor fireclay, the NGR readings ranged from 5,133 to 6,711 cpm, with a mean value of 5,595 cpm. For rock partings, the NGR readings ranged from 3,937 to 5,433 cpm, with a mean value of 4,844 pm. The mean NGR reading of the ambient air was 3,564 cpm. The R:C ratio at these locations ranged from 1.44 to 5.76, with a mean value of 2.70; the F:C ratio ranged from 1.65 to 356, with a mean value of 2.39; and the P:C ratio ranged from 1.47 to 3.08, with a mean value of 2.07 (table 12).

### Laboratory Testing

Laboratory tests of 25 coal and rock samples obtained from several locations in this mine showed small variations in the NGR readings. When the ESP-2 was used, the mean values were: seven roof samples, 2,568 cpm; seven coal samples, 1,532 cpm; six floor samples, 2,012 cpm; and five rock partings, 1,982 cpm. The mean R:C ratio was 1.68, the F:C ratio was 1.31, and the P:C ratio was 1.29. Using the GRS-500, the R:C ratio was 1.53, the F:C ratio was 1.32, and the P:C ratio was 1.01 (table 13).

KUT radiometric analysis of one roof sample indicates that the bulk density was 1.76 g/cc, RaeU was 3.50 ppm, Th was 8.08 ppm, and K-40 was 1.59%. For one coal sample, bulk density was 0.89 g/cc, RaeU was 0.67 ppm, Th was 3.25 ppm, and K-40 was <10% For one floor sample, bulk density was 1.28 g/cc, RaeU was 3.87 ppm, Th was 6.36 ppm, and K-40 was 0.54%. NGR testing in the laboratory indicates that NGR for the roof sample was 1,517 cpm, for the coal sample it was 1,113 cpm, and the floor sample was too small for testing (tables 16 to 18).

Six coal and ten rock samples were analyzed for ash, sulfur, and heating value. Ash content of the coal samples ranged from 4.84% to l3.26% (mean 8.40%); sulfur content ranged from 0.43% to 1.10% (mean 059%); and heating value ranged from 12,462 to 13,825 Btu/lb (mean 13,260 Btu/lb). One floor sample had 3.01% sulfur (table l5).

## WADGE COAL SEAM

A visit was made to a mine in Wadge Coal Seam, Colorado, to observe the RHC 801 unit in operation on a longwall shearer, to collect coal, roof, and floor samples, and to make NGR measurements of coal and surrounding strata wherever possible. The immediate roof is relatively hard, gray to dark gray laminated shale and silty mudstone that becomes very fractured when exposed to air and moisture. It is occasionally mixed with bony coal. The mean seam thickness is 3,048 mm (120 in). Occasionally, some rock partings up to 305 mm (12 in) thick are found in the coal seam. The bottom of the coal is high in ash. The immediate floor is composed of water-sensitive mudstone mixed with bony coal.

The mine was designed to produce about 3 million st of coal/yr via longwall mining, with a computerized high-capacity conveyor belt system to maintain high production of clean coal (7). The dimensions of the longwall panels are approximately 195 m (640 ft) wide by 2,743 m (9,000-ft) long.

### Underground Testing

Underground NGR measurements were made at six locations using the ESP-2 For the roof shale, NGR readings ranged from 7,787 to 10,333 cpm, with a mean value of 9,588 cpm. For coal, the NGR readings ranged from 3,183 to 4,803 cpm, with a mean value of 4,256 cpm. For the floor mudstone, NGR readings ranged from 5,033 to 7,950 cpm, with a mean value of 6,331 cpm. [Note: Because 152 to 305 mm (6 to 12 in) of coal was generally left on the floor, direct NGR readings for the floor mudstone were not possible.] For ambient air, the mean NGR reading was 6,320 cpm, which is only 6% less than the mean value of roof, coal, and floor combined. The mean R:C ratio was 2.25 and F:C ratio was 1.49 (table 12).

The RHC 801 was successfully used on the longwall shearer in the mine for over five months for the purpose of controlling the thickness of the coal left on the roof. The RHC indicator was calibrated to leave 203 mm (8 in) of coal, but it generally indicated that about 254 mm (10 in) of coal was being left. After starting to use the RHC 801 [leaving 203 to 254 mm (8 to 10 in) of roof coal], roof control conditions at the face improved and the ash content in the run-of-mine coal was reduced from 11.24% to 12.25% to approximately 10% as required by the customer's contract.

### Laboratory Testing

Laboratory tests using the ESP-2 for 13 coal and rock samples collected indicated that the mean R:C was 1.60 (excluding the bony coal roof) and was 1.58 (including the bony coal roof). Using the GRS-500, the R:C was 1.48 and the F:C was 1.58 (table 13).

KUT radiometric analysis of one coal sample indicates that the bulk density was 0.92 g/cc, RaeU was 0.39 ppm, Th was 0.95 ppm, and K-40 was <0.10%. For one floor sample, the bulk density was 1.21 g/cc, RaeU was 5.44 pm, Th was 13.70 ppm, and K-40 was 2.28%. No roof sample was available for testing. NGR testing in the laboratory indicates that for the coal sample it was 1,213 cpm and for the floor sample it was 1,730 cpm (tables 17, 18).

Seven coal and six rock samples were collected at six locations near the longwah face and development entries. Ash content of 7 coal samples ranged from 3.65% to 11.04% (mean 6.40%); sulfur content ranged from 0.34% to 1.44% (mean 0.54%); and heating value ranged from 12,264 to 13,427 Btu/lb (mean 13,030 Btu/lb). The mean R:C ratio was 2.50 (excluding the bony coal roof) and 2.21 (with the bony coal roof). For the mudstone floor mixture, the F:C ratio was 1.42 (table 15).

## ADDITIONAL NGR EVALUATION TESTS

Additional underground, laboratory NGR, and KUT measurements and geologic sample collections were made in the Eastern and Rocky Mountain geological provinces at five underground mines located in two major and three other coal seams. The purpose of these measurements was to determine if an NGR system can be used effectively in these mines to control the roof coal thickness during mining. The results of the underground and laboratory NGR measurements for these five mines are given in table 19 and the chemical analyses are given in table 20. For KUT radiometric analysis, the results are given in tables 16 to 18.

### PITTBURGH COAL SEAM

A visit was made to a mine operating in the Pittsburgh Coal Seam in southwestern Pennsylvania. The immediate roof is composed of draw slate and shale of variable thicknesses. Roof parting occasionally thins from 635 mm (25 in) to 30 mm (1.2 in) and appears to be squeezed and fractured. Rider coal, which is above the parting, is of variable thickness and ranges from 25 to 356 mm (1 to 14 in). The main coal seam is from 1,778 to 1,828 mm (70 to 72 in) thick. In most cases, the seam in the mine is penetrated by clay veins (dikes) of variable thicknesses. Occasionally, small faults with clay veins are noted along the longwall face. The immediate floor strata is hardpan, 152 to 203 mm (6 to 8 in) thick, beneath which is fireclay.

### Underground Testing

Underground NGR data were obtained at three locations using the ESP-2 and GRS-500 units (table 19). Using the ESP-2 unit, the roof shale mean NGR reading was 9,499 cpm; the roof coal was 6,445 cpm; the main coal was 4,509 cpm; the roof parting was 9,101 cpm; and the immediate floor was 10,796 cpm. The mean roof-to-top-rider coal (R:TRC) ratio was 1.47. For the GRS-500 unit (TCl level) the R:TRC ratio was 1.37. For the roof parting-to-main coal (RP:MC) with ESP-2 unit, the mean ratio was 2.02, with the GRS-500, the RP:MC ratio was 1.58. The mean floor-to-main coal (F:MC) ratio with ESP-2 was 2.66 and with GRS-500 the F:MC ratio was 1.81.

### Laboratory Testing

ESP-2 laboratory measurements of six samples obtained from the mine indicate that the NGR reading for roof shale was 3,940 cpm; for roof coal it was 2,240 cpm; for main coal it was 2,283 cpm; for parting it was 4,020 cpm; and for immediate floor it was 4,137 cpm. The R:TC and RP:MC ratios were each 1.76, and the F:MC ratio was 1.53. Using the GRS-500 unit, the R:TC ratio was 1.49; the RP:MC ratio was 1.34; and the F:MC ratio was 2.22 (table 19).

KUT radiometric analyses of two roof samples indicate that the bulk density was 1.61 and 1.64 g/cc, RaeU was 4.83 and 5.38 ppm, Th was 19.40 and 19.50 ppm, and K-40 was 1.90% and 1.57%, respectively. For these two coal samples, the bulk density was 0.93 and 1.04 g/cc, RaeU was 0.50 and 1.43 ppm, Th was 0.80 and 4.61 ppm, and K-40 was ~0.10% and 0.32%, respectively. Two floor samples had bulk densities of 1.72 and 1.50 g/cc, RaeU was 3.10 and 7.18 ppm, Th was 15.20 and 14.60 ppm, and K-40 was 2.07% and 1.67%, respectively. NGR readings

Table 19.—Underground and laboratory NGR measurements (cpm) taken at five coal seams

| Coal seam | Location | Underground | | | Laboratory | | |
|---|---|---|---|---|---|---|---|
| | | ESP-2 | GRS-500 | | ESP-2 | GRS-500 | |
| | | | TC1[1] | TC2[2] | | TC1[1] | TC2[2] |
| Pittsburgh | Imm. roof | 9,499 | 21,832 | 3,828 | 3,940 | 4,502 | 1,248 |
| | Roof coal | 6,445 | 17,107 | 2,821 | 2,240 | 3,208 | 792 |
| | Coal | 4,509 | 13,706 | 2,029 | 2,283 | 2,526 | 774 |
| | Parting | 9,101 | 21,605 | 3,958 | 4,020 | 4,703 | 1,212 |
| | Imm. floor | 10,796 | 22,292 | 4,073 | 4,137 | 5,600 | 1,504 |
| | Background | 7,809 | 19,334 | 3,238 | 1,560 | 2,270 | 752 |
| Freeport | Imm. roof | 9,781 | 19,283 | 3,552 | 2,817 | ND | ND |
| | Roof coal | 7,026 | 17,513 | 3,113 | 2,317 | 3,314 | 894 |
| | Coal | 4,284 | 13,163 | 1,978 | 1,826 | 2,906 | 790 |
| | Floor fireclay | 12,289 | 24,929 | 4,605 | 3,420 | 4,270 | 1,222 |
| | Background | 8,271 | 17,777 | 3,037 | 1,668 | 2,282 | 755 |
| Maxwell | Imm. roof | 9,336 | 22,034 | 4,057 | 2,977 | 4,145 | 1,094 |
| | Roof coal | 6,146 | 14,362 | 2,196 | ND | ND | ND |
| | Main coal | 4,184 | 14,350 | 2,058 | 1,703 | 2,758 | 831 |
| | Floor shale | 10,933 | 22,955 | 4,037 | ND | ND | ND |
| | Background | 7,162 | 17,509 | 2,881 | 1,637 | 2,234 | 708 |
| B Seam | Imm. roof | 7,873 | ND | ND | 3,227 | 4,640 | 1,245 |
| | Top head coal | 1,541 | 4,380 | 678 | 1,653 | 3,302 | 824 |
| | Main coal | 1,653 | 4,533 | 615 | 1,633 | 3,305 | 840 |
| | Parting | 2,521 | 6,464 | 918 | 2,193 | 3,684 | 950 |
| | Floor coal | 2,231 | 5,478 | 822 | ND | ND | ND |
| | Background | 1,845 | 5,052 | 744 | 1,453 | 2,186 | 695 |
| Upper Left Fork | Imm. roof | 10,550 | 20,769 | 4,044 | 4,387 | ND | 1,416 |
| | Top coal | 7,004 | 17,190 | 2,997 | ND | ND | ND |
| | Roof coal below: | | | | | | |
| | Parting 1 | 4,022 | 12,197 | 1,823 | ND | ND | ND |
| | Main coal | 3,858 | 12,923 | 1,894 | 1,963 | 3,614 | 876 |
| | Parting 2 | 6,152 | 15,686 | 2,644 | 3,133 | 3,444 | 996 |
| | Imm. floor | 9,763 | 20,547 | 3,875 | 4,080 | 6,642 | 1,662 |
| | Background | 6,037 | 15,344 | 2,487 | 1,730 | 2,271 | 750 |

ND No data.
[1]Total counts above 0.08 MeV.
[2]Total counts above 0.40 MeV

for two roof samples were 1,453 and 1,550 cpm, for two coal samples were 1,100 and 1,240 cpm, and for two floor samples were 1,433 and 1,667 cpm (tables 16 to 18).

The results of chemical analyses of four coal and rock samples indicate that the ash content of the roof coal was 5.97% and of the main coal was 12.53%; the sulfur content of the roof coal was 2.75% and of the main coal was 5.00%; the heating value of the top coal was 14,297 Btu/lb and of the main coal was 12,843 Btu/lb (table 20).

## FREEPORT COAL SEAM

A visit was made to a mine operating in the Lower Freeport Coal Seam in Ohio. The immediate roof strata are composed of laminated gray sandstone, occasionally mixed with shale. The mean seam thickness is about 1,778 mm (70 in) and ranges from 1,422 to 1,905 mm (56 to 75 in). The top 152 to 254 mm (6 to 10 in) of coal has up to 21% ash and up to 10% sulfur. Because of the high ash and sulfur content of the top coal, up to 254 mm (10 in) of coal is typically left on the roof. The immediate floor is made up of hard gray fireclay, beneath which is solid limestone.

### Underground Testing

Underground NGR measurements were made at three locations (table 19). Using the ESP-2 unit, the NGR count rates were 9,781 cpm for roof shale; 7,026 cpm for roof coal; 4,284 cpm for main coal; and 12,289 cpm for floor fireclay. The mean R:TC ratio was 1.43; the mean R:MC ratio was 2.41; and the mean F:MC ratio was 3.00. For the GRS-500 unit (TC1 level), the mean R:TC ratio was 1.10; the mean R:MC ratio was 1.46; and the mean F:MC ratio was 1.89.

### Laboratory Testing

Laboratory measurements of four samples using ESP-2 indicate that the NGR count rate was 2,817 cpm for roof sandstone; 2,317 cpm for roof coal; 1,826 cpm for main coal; and 3,420 cpm for floor fireclay. The R:TC ratio was

Table 20.—Laboratory analyses of one sample from each of five coal seams

| Coal seam | Chemical analyses | | | NGR, cpm | | |
|---|---|---|---|---|---|---|
| | Ash content, % | Sulfur content, % | Heating value, BTU/lb | ESP-2 | GRS-500 | |
| | | | | | TC1[1] | TC2[2] |
| Pittsburgh: | | | | | | |
| Roof | 92.27 | 1.17 | 104 | 3,940 | 4,502 | 1,248 |
| Top coal | 5.97 | 2.75 | 14,297 | 2,240 | 3,028 | 792 |
| Parting | 84.21 | 0.50 | 1,326 | 4,020 | 4,708 | 1,212 |
| Main coal | 12.53 | 5.00 | 12,843 | 2,283 | 3,526 | 774 |
| Freeport: | | | | | | |
| Roof | 90.67 | 3.09 | 658 | 1,817 | ND | ND |
| Top coal | 23.79 | 11.15 | 10,883 | 2,317 | 3,314 | 894 |
| Main coal | 7.87 | 4.08 | 13,386 | 1,826 | 2,906 | 790 |
| Floor fireclay | 92.74 | 0.86 | 320 | 3,420 | 4,270 | 1,222 |
| Maxwell: | | | | | | |
| Roof | 70.26 | 0.16 | 3,744 | 2,977 | 4,145 | 1,094 |
| Coal | 5.23 | 0.36 | 14,607 | 1,703 | 2,758 | 831 |
| B Seam: | | | | | | |
| Roof | 91.39 | 1.53 | 594 | 3,227 | 4,640 | 1,245 |
| Head coal | 5.11 | 0.63 | 13,572 | 1,653 | 3,302 | 824 |
| Main coal | 6.27 | 0.56 | 13,528 | 1,633 | 3,305 | 840 |
| Parting | 79.51 | 0.17 | 1,769 | 2,193 | 3,684 | 950 |
| Upper Left Fork: | | | | | | |
| Roof | 93.53 | 0.05 | 80 | 4,387 | 6,018 | 1,416 |
| Coal | 12.02 | 0.45 | 13,185 | 1,963 | 3,624 | 876 |
| Parting | 61.68 | 0.22 | 5,138 | 3,133 | 3,444 | 996 |
| Floor | 90.80 | 0.21 | 578 | 4,080 | 6,642 | 1,662 |

ND No data.
[1]Total counts above 0.08 MeV.
[2]Total counts above 0.40 MeV.

1.27; the R:MC ratio was 1.42, and the F:MC ratio was 1.89. When using GRS-500 unit (TC1 setting), the R:TC ratio was 1.27; the R:MC ratio was 1.42; and the F:MC ratio was 1.89 (table 19).

The results of chemical analyses of four coal and rock samples show that the ash content of the roof coal was 23.79% and the main coal was 7.87%. The sulfur content of the roof coal was 11.15% and the main coal was 4.08%. The heating value for the roof coal was 10,883 Btu/lb and the main coal was 13,386 Btu/lb (table 20).

## MAXWELL COAL SEAM

A visit was made to a mine operating in the Maxwell Coal Seam in Colorado. The immediate roof strata in the mine are composed of gray, soft slickensided shale, occasionally mixed with sandstone. The mean seam thickness is 2,134 mm (84 in) and ranges from 1,372 to 2,743 mm (54 to 108 in). The seam occasionally has clay veins of different thicknesses. The immediate floor strata are made up of soft, water-sensitive fireclay. To protect the soft roof strata, from 203 to 305 mm (8 to 12 in) of coal are left on the roof.

### Underground Testing

Underground NGR measurements were made at three locations (table 19). Using the ESP-2 unit, the mean NGR count rates were 9,336 cpm for roof shale; 6,146 cpm for roof coal; 4,184 cpm for main coal; and 10,933 cpm for floor shale. The mean R:TC ratio was 1.52; the mean R:MC ratio was 2.23; and the mean F:MC ratio was 2.61. When using the GRS-500 (TC1 setting), the mean R:TC ratio was 1.69 and the mean R:MC and F:MC ratios were each 1.54.

### Laboratory Testing

Laboratory measurements of two samples using the ESP-2 indicate that the NGR count rate for roof shale was 2,977 cpm and for main coal was 1,703 cpm. The R:MC ratio was 1.75. When using the GRS-500 (TC1 setting), the R:MC ratio was 1.54 (table 19).

KUT radiometric analysis of one roof sample indicates that the bulk density was 1.30 g/cc, RaeU was 7.11 ppm, Th was 19.20 ppm, and K-40 was 1.56%. One coal sample had a bulk density of 0.88 g/cc, RaeU of 1.25 ppm, Th of

333 ppm, and K-40 of <0.10%. No floor sample was available for testing. The NGR reading of that roof sample was 2,167 cpm and of that coal sample was 1,273 cpm (tables 16,17).

The chemical analysis of one sample from the main coal indicates that the ash content was 5.23%; the sulfur content was 036%; and the heating value was 14,607 Btu/lb (table 20).

## B COAL SEAM

A visit was made to a mine in the B Coal Seam in Colorado. The immediate roof strata are composed of dark gray shale, generally about 0.61 m (2 ft) thick. The seam itself can be up to 7.62 m (25 ft) thick. The unmined (head) coal is up to 1,016 mm (40 in) thick and includes banded and unbanded coal occasionally mixed with pyrite. Between the head coal and main coal there is a 76- to 102-mm (3 to 4-in)-thick rock parting with bony coal (marker parting) that is normally left on the roof. Up to 4.27 m (14 ft) of the upper coal will be mined during the operation; the remaining coal [up to 3.09 m (10 ft)] will be left on the floor. Occasionally, a rock parting of variable thickness is found in the floor coal.

### Underground Testing

Underground NGR measurements were made at five locations (table 19). The results using the ESP-2 unit indicate that the mean count rate was 7,873 cpm for the immediate roof strata; 2,521 cpm for the roof parting near the roof; 1,541 cpm for roof coal, 1,653 cpm for main coal; 2,321 cpm for floor coal; and 4,533 cpm for floor partings. The mean R:TC ratio was 5.11; the R:MC ratio was 4.76; and the RP:MC ratio was 1.53. Similar trends in the NGR count rates were obtained when the GRS-500 unit was used. However, ratios based on the GRS-500 measurements could not be computed because it was not possible to take NGR readings of the immediate roof strata because it was inaccessible at the time. For GRS-500, the RP:RC ratio was 148 and the RP:MC ratio was 1.43. NGR measurements of the floor strata could not be made with either unit.

### Laboratory Testing

NGR laboratory measurements of four rock and coal samples indicate that when using the ESP-2 unit the NGR count rate was 3,227 cpm for the roof shale; 1,653 cpm for roof coal; 2,193 cpm for a rock parting near the roof; and 1,633 cpm for the main coal. The R:TC ratio was 1.95; the R:MC was 1.98; and the RP:MC was 1.34. When using the GRS-500 (TCl setting), the R:TC ratio was 1.41 and the RP:MC was 1.11 (table 19).

KUT radiometric analysis of one roof sample indicates that the bulk density was 1.71 g/cc, RaeU was 3.97 ppm, Th was 16.70 ppm, and K-40 was 2.70%. For one coal sample the bulk density was 0.91 g/cc, RaeU was 0.35 ppm, Th was 0.77 ppm, and K-40 was <0.10%. No floor sample was available for testing. The NGR reading of one roof sample was 2,133 cpm and of one coal sample was 1,190 cpm (tables 16, 17).

Chemical analyses of one roof coal and one main coal sample indicate that the ash content was 5.11% and 6.27%; sulfur content was 0.63% and 056%; and heating value was 13,572 and 13,528 Btu/lb, respectively (table 20).

## UPPER LEFT FORK COAL SEAM

A visit was made to a mine operating in the Upper Left Fork Coal Seam in New Mexico. The immediate roof strata are composed of shale and mudstone, occasionally mixed with sandstone. The seam thickness ranges from 1,829 to 2,794 mm (72 to 110 in), with a mean value of 2,438 mm (% in). From one to three rock partings are found in the seam, having a combined total thickness from 78 to 610 mm (7 to 24 in). The immediate floor is soft to medium hard shale and mudstone. The mining company would like to leave up to 508 mm (20 in) of coal on the roof during mining to protect weak roof strata.

### Underground Testing

Underground NGR measurements were made at three locations. Using the ESP-2 unit, the results indicate that the mean NGR count rate was 10,550 cpm for the immediate roof shale; 7,004 cpm for roof coal, 4,022 cpm for roof coal below the parting; and 3,858 cpm for main coal. For the roof parting the rate was 6,152 cpm and for the floor shale the rate was 9,763 cpm. The mean R:TC ratio was 1.50, for roof coal under the parting, the R:TC ratio was 2.62; the R:MC ratio was 2.73; and the F:MC ratio was 2.54. When using the GRS-500 unit (TCl setting), the mean R:TC ratio was 1.21, for roof coalunder parting, the R:TC ratio was 1.70; the R:MC ratio was 1.61; and the F:MC ratio was 1.59 (table 19).

### Laboratory Testing

Laboratory measurements of four samples indicate that using the ESP-2 unit, the NGR count rate was 4,387 cpm for roof shale; 1,963 cpm for main coal, 3,133 cpm for rock parting; and 4,080 cpm for floor shale. The R:MC ratio was 2.23; the P:MC ratio was 1.60; and the F:MC ratio was 2.08. When using the GRS-500 (TCl setting), the R:MC ratio was 1.66, the F:MC ratio was 1.83, and the P:MC ratio was 1.60 (table 19).

KUT radiometric analysis of one roof sample indicate that the bulk density was 1.62 g/cc, RaeU was 5.81 ppm, Th was 18.50 ppm, and K-40 was 2.22%. One coal sample had a bulk density of 0.89 g/cc, RaeU of 0.66 ppm, Th of 1.78 ppm, and K-40 of ~0.10%. One floor sample had a bulk density of 0.80 g/cc, RaeU of 0.90 ppm, Th of 253 ppm, and K-40 of <0.10%. NGR testing in the laboratory indicated that one roof sample had 2,338 cpm, one coal sample had 1,173 cpm, and one floor sample had 1,230 cpm (tables 16 to 18).

Four coal and rock samples were analyzed for ash content, sulfur content, and heating value. The ash content of the sample from the main coal was 12.02%, the sulfur content was 0.45%, and the heating value was 13,185 Btu/lb (table 20).

## NGR SYSTEMS IN OPERATION AT MINE SITES

A number of NGR systems were used at underground and highwall coal mines and also at a trona ash mine during the period 1993 to 1995. As of August 1995, the number of AME` units in the field was 34, of which two were CM2000 systems (i.e., a new microprocessor-based version of the AME 1008 with an inclinometer for continuous miner). Data obtained from 11 mines indicate that the number of units fluctuated from 17 to 21. Of these, 20 were AME units and 1 was a RHC unit. Table 21 lists known NGR systems installed on mining machines in the United States as of August 1995.

These NGR systems were used in eight different coal seams in seven states. One NGR unit is being used at a trona mine to monitor up to 102 mm (4 in) of trona left on the floor. One other trona mine has ordered two NGR units.

Both the AME and RHC systems use scintillation crystals and are capable of providing coal thickness measurements on the order of 0 to 508 mm (0 to 20 in). This must be left below the roof or above the floor to protect poor roof or weak floor strata, or to avoid removal of roof or floor coal with high ash and/or sulfur content.

In order to determine the feasibility of using the NGR techniques in the United States, the USBM has analyzed geological and mining data for over 460 underground and surface mines. Information obtained indicated that approximately 90% of the mines have an immediate roof and/or floor composed of shaley-type materials, which typically have higher radioactive levels than coal.

NGR systems have been used successfully on both longwall shearers and continuous miners in underground operations and also on highwall miners in surface operations. The systems work best when the speeds are less than 15 m/min (50 ft/min), and coal left is 152 to 203 mm (6 to 8 in). If the speed of the shearer is 24 m/min (80 ft/min) or higher, it is very difficult for the operator to read the NGR data without a remote indicator. The units are mounted between 203 to 406 mm (8 to 16 in) from the roof or floor coal. The airgap between the NGR units and the roof or floor coal ranges from 76 to 762 mm (3 to 30 in).

The NGR units have been used for measuring from 51 to 610 mm (2 to 24 in) of coal left on the roof and from 51 to 127 mm (2 to 5 in) or up to 610 m (24 in) on the floor. When the thickness of the coal to be left on the roof is thicker than 610 mm (24 in) or more [which is beyond the normal 508- to 610-mm (20- to 24-in) range], the NGR units cannot be applied. The best results are obtained when the thickness of the coal left is in the range of 152 to 305 mm (6 to 12 in), and the variation of the thickness and geology of the immediate roof and floor strata, as well as the variation in the seam thickness, is small. Also, the seam should be flat or only with a small dip. The NGR units can also be calibrated to indicate that no coal is left on the roof.

Problems encountered when using the NGR units were

- nonshaiey roof or floor
- remnant coal too thick for sensor to read NGR
- geology too variable
- inadequate training of personnel
- decreased accuracy (due to decreased NGR counts)
- mining debris buildup on NGR sensor
- damaged cables and/or connectors of NGR system
- moisture accumulation in system due to -cleaning equipment of high-pressure water spray
- longwall shearer speed too high **[> 15 m/min (>50 ft/min)].**

Table 21.—NGR sensors operating in U.S. mines (as of August 1995)

| Mine No. | Coal seam | State | Miner type | NGR system type | Location | Range, cm | In use | Comments |
|---|---|---|---|---|---|---|---|---|
| 1 ....... | Pittsburgh | PA | CM | 1008 | F | 20 | Yes | O.K. |
| 1 ....... | Pittsburgh | PA | CM | 1008 | F | 20 | Yes | O.K. |
| 1 ....... | Pittsburgh | PA | CM | 1008 | F | 20 | Yes | O.K. |
| 1 ....... | Pittsburgh | PA | CM | CM2000 | F | 20 | No | Idle. |
| 2 ....... | No. 38 | WY | HW | 1016 | R | 46-51 | Yes | O.K |
| 2 ....... | No. 38 | WY | HW | 1016 | R | 30-36 | No | Standby. |
| 2 ....... | No. 38 | WY | HW | 1016 | F | 20-25 | Yes | O.K. |
| 3 ....... | Hanna | WY | LS | 1016 | R | 46-91 | Yes | When <61 cm. |
| 3 ....... | Hanna | WY | CM | CM2000 | F | 30 | No | Not installed. |
| 4 ....... | Wadge | CO | LS | 1008 | R | 15-25 | No | High LS speed. |
| 5 ....... | No. 6 | IL | LS | 1016 | R | 8-10 | No | Thin seam. |
| 5 ....... | No. 6 | IL | CM | 1008 | R | 20 | Yes | O.K. |
| 5 ....... | No. 6 | IL | CM | 1008 | R | 20 | Yes | O.K. |
| 6 ....... | Pittsburgh | PA | CM | 1008 | R | 15-20 | Yes | O.K. |
| 6 ....... | Pittsburgh | PA | CM | 1008 | R | 15-20 | No | Standby. |
| 7 ....... | O'Connor | UT | CM | 801 | R | 61-91 | No | Thin seam. |
| 8 ....... | No. 13 | KY | LS | 1016 | R | 5-15 | No | Remote control. |
| 9 ....... | Trona | WY | EBM | 1008 | F | 2.5-10 | Yes | O.K. |
| 10 ...... | Trona | WY | LS | 1008 | R | 15-25 | No | Not installed. |
| 10 ...... | Trona | WY | EBM | 1008 | F | 0+ | No | Not installed. |
| 11 ...... | Freeport | OH | CM | CM2000 | F | 2.5-15 | Yes | O.K. |

NOTE.—Nomenclature:

Location:
F floor
R roof

Miner type:
CM continuous miner
EBM Eimco boring machine
HW highwall miner
LS longwall shearer

NGR system manufacturer:
AME 1008, 1016, CM2000
RHC 801

## SUMMARY

Presently there are four commercially available NGR sensors that are MSHA approved for installation on mining machinery—the RHC 801, RHC 803, AME 1008, and the AME 1016. However, the AME 1016 was not available for testing. The physical dimensions of these sensors are basically similar, being approximately 635 by 203 by 152 mm (25 by 8 by 6 in). The RHC 803 is designed for use on a continuous miner; however, all four units could be used on either longwall shearers or continuous miners. Both RHC units operate on either 440 to 550 or 880 to 1,100-V, 3-phase, ac power, and can also operate on batteries. The AME units operate either on 110 to 120 V, ac power, or batteries.

All of the NGR sensors work best within a range of approximately 76 to 305 mm (3 to 12 in) of roof coal, although vendors claim sensors can work for up to 508 mm (20 in) of roof coal. These sensors should preferably have no more than 910 mm (3 ft) of airgap between the roof and the sensor to maintain adequate sensitivity. It was also found that the NGR values dropped rapidly during the first 305 mm (12 in) of airgap.

For the NGR-based CID technique to work properly, the immediate roof or floor must be composed of a gamma-emitting material such as shale, draw slate, or fireclay. In addition, minimum thickness of the immediate roof or floor should be at least 76 mm (3 in), based on the results of laboratory tests. Also, the immediate roof or floor should remain relatively constant in geological composition for best results.

Based on underground tests conducted at the USBM SRCM mine (Pittsburgh Coal Seam), the AME 1008 appears to be about 2.4 times more sensitive than the RHC 801, and the RHC 803 is approximately 88% as sensitive as the RHC 801. The AME 1016 was not available for testing. The ESP-2 is about 53% as sensitive and the GRS-500 is approximately 1.4 times more sensitive than the RHC 801. Consequently, if the ESP-2 is used for preliminary underground tests, the values given by the ESP-2 can be multiplied by 1.89, 1.66, and 4.41, to obtain estimated values for the RHC 801, RHC 803, and AME 1008, respectively.

For testing in the laboratory, coal and rock samples should be at least 76 mm (3 in) thick, have at least 161.3 $cm^2$ (25 $in^2$) of surface area exposed, and should weigh at least 1,814 g (4 lbs) in order to get a reasonably good NGR measurement. In general, the larger the sample, the better the NGR reading. Ideally, the samples should be made identical in physical size and weight. Efforts are being directed toward determining a standard size sample container so that all samples are identical in terms of physical dimensions. The samples would be ground to at least 60-mesh size and then poured into the sample container.

Underground and laboratory NGR values as measured by the ESP-2 were found to have a relatively wide range for the coal seams studied in this report, e.g., the underground/laboratory ratio values ranged from 1.53 to 5.58. Consequently, it is not yet possible to obtain a general conversion factor for relating laboratory NGR counts to underground counts, although a ratio value of 3.5 could be used as an initial approximation. More underground and laboratory measurements are needed to provide a more accurate ratio value for a given coal seam.

For the coal seams studied, the Illinois No. 5 had the highest roof NGR count rate and the Hiawatha had the lowest, based on underground measurements using the ESP-2.[6]

Ratios of underground NGR readings were computed, e.g., R:C and F:C. Basically, the higher this ratio, the better likelihood that the NGR technique would work. R:C values ranged from 1.41 (Kittanning) to 3.08 (Illinois No. 5). F:C values ranged from 1.45 (Kittanning) to 2.39 (Hiawatha). Consequently, a roof NGR sensor appears to have the best chance of success if used in the Illinois No. 5 coal seam and a floor NGR sensor is most likely to work best if used in the Hiawatha coal seam.

Based on coal and rock data collected by USBM personnel, it is currently believed that R:C and F:C ratios on the order of at least 1.5 are needed for successful implementation of the NGR technique. However, this critical minimum value has not been able to be objectively determined because there is very little underground operational data available as yet.

KUT radiometric analysis of 17 roof rock, 16 coal, and 12 floor rock samples, obtained from 18 mines representing 16 coal seams in different coal regions, was done by the U.S. Geological Survey, Branch of Isotope Geology, Denver, Colorado. These samples were selected from mines where the AME and RHC units were used (or presently are in use), from mines where USBM personnel have performed in-mine NGR testing for CID purposes, and from those mines where laboratory or in-mine NGR readings were significantly higher than normal.

The results of these 45 coal and rock samples are listed in tables 16 to 18, with units being given in percent for potassium and in part per million for uranium and thorium; also, 29 of these samples also had a chemical analysis done. It should be noted that the roof samples from Illinois No. 5 and No. 6 Seams, and Kentucky No. 9 Seam, have higher than normal uranium concentration (table 16). This was expected because these samples also had higher NGR readings for both the underground and laboratory testing.

[6]The Clarion Coal Seam had the lowest apparent NGR count rate; however, the ESP-2 was operated in a narrow--window mode rather than a wide-window mode for this particular seam. For that reason, these values cannot be compared to the others.

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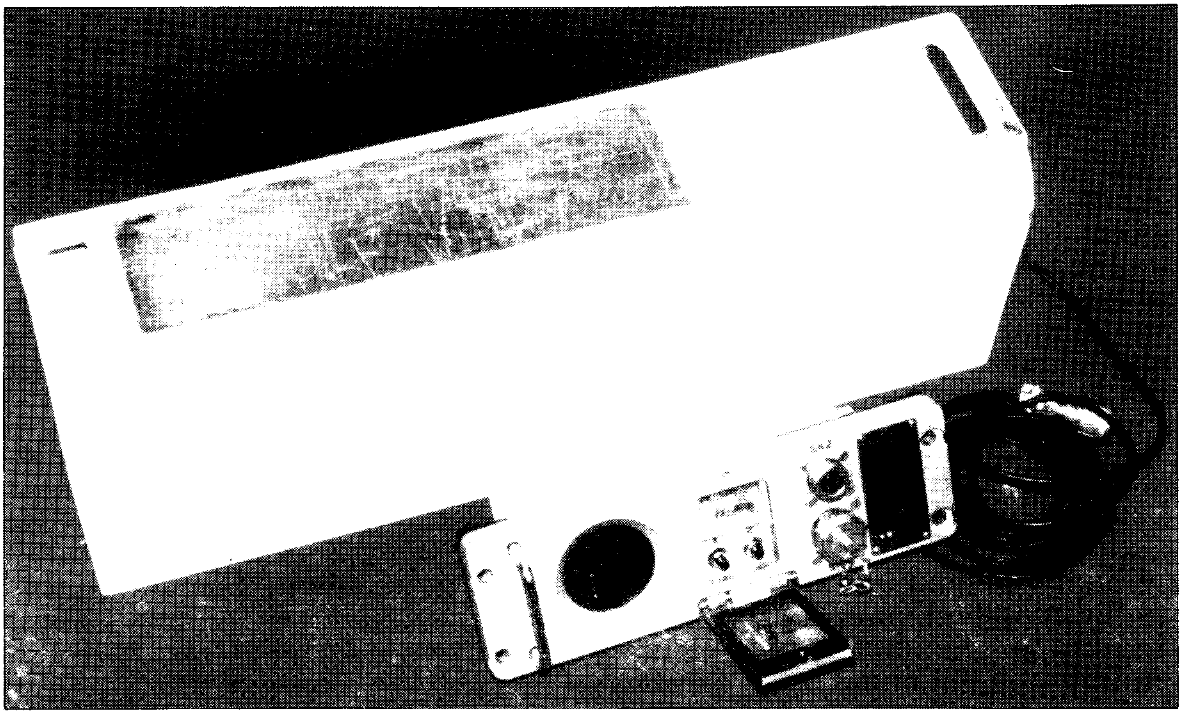
6. EDA Instruments Inc. (Toronto, Ontario, Canada). Brochure, Scintrex, GRS-500 Differential Spectrometer/Scintillometer, 1988, 4 pp.

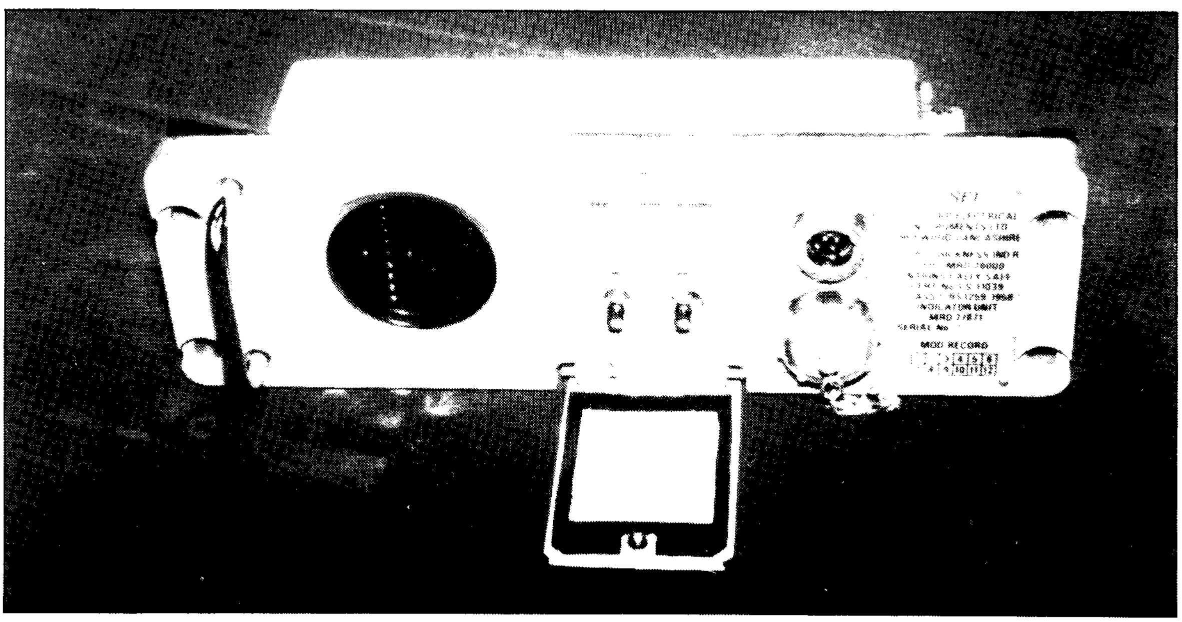
7. Hanna, K., K. Haramy, and T. R Ritzel. Automated Longwall Mining for Improved Health and Safety at the Foidel Creek Mine. SME Annual Meeting, Denver, CO, Feb. 25-28, 1991, SME Preprint 91-165, 1991, 8 pp.

*Figure 1*



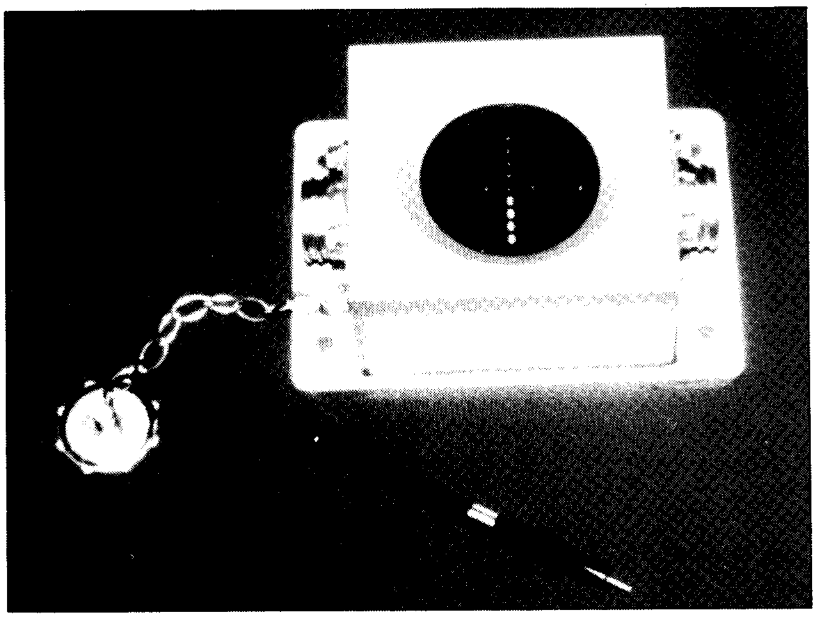
*RHC 801 natural gamma probe and coal thickness indicator unit.*

*Figure 2*



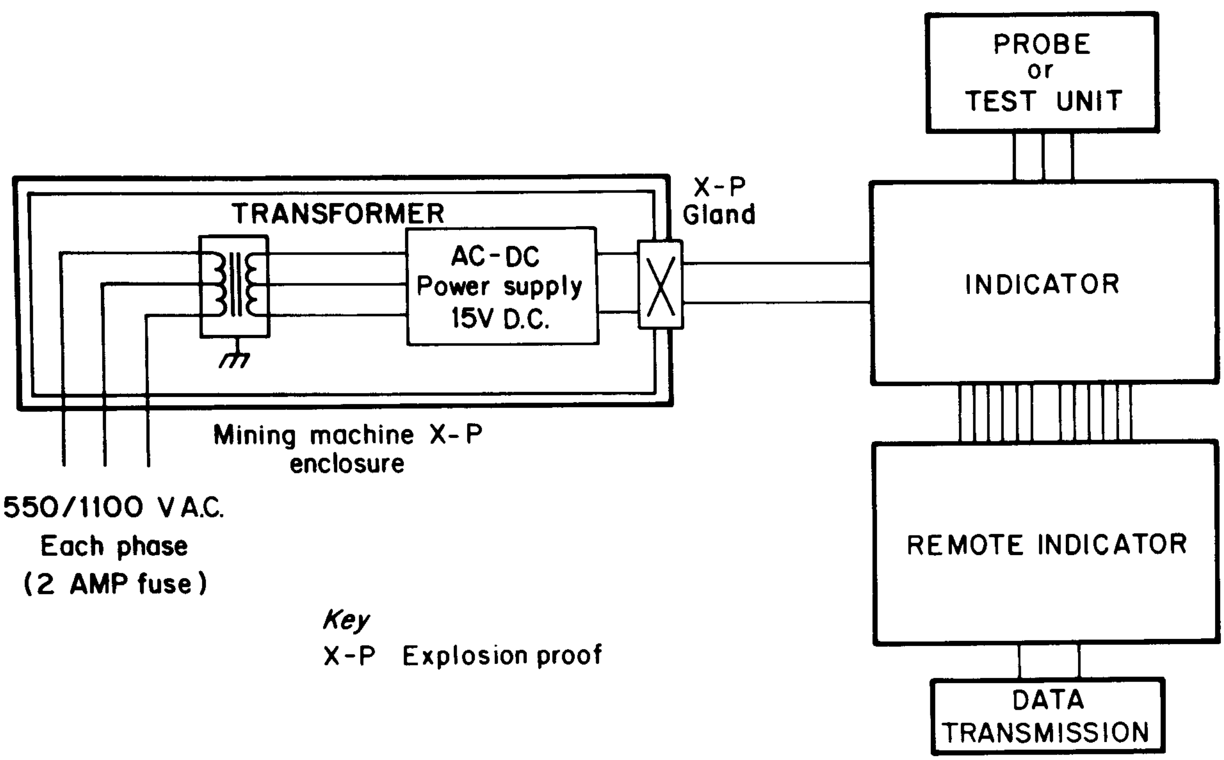
*Coal thickness indicator unit for RHC 801 probe.*

*Figure 3*



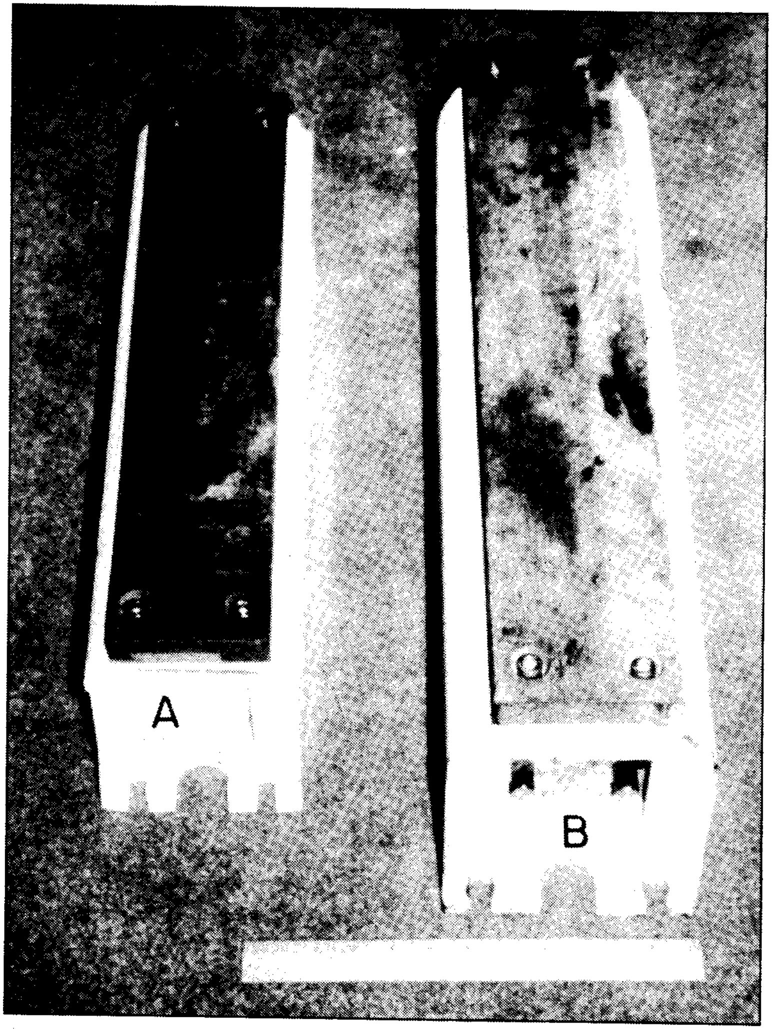
*Remote indicator unit for RHC 801 probe.*

*Figure 4*



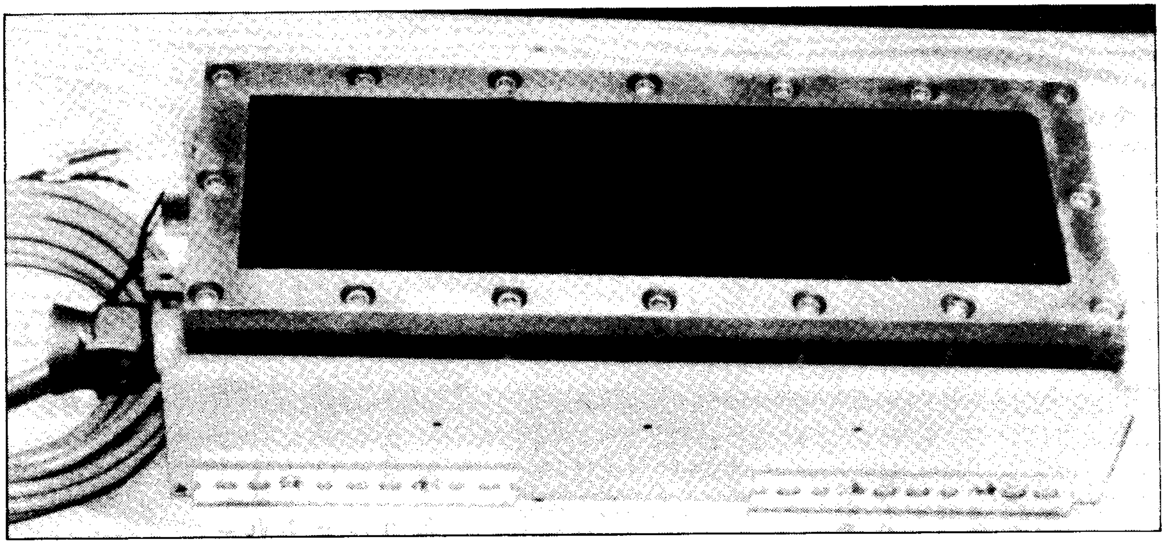

*Block diagram for RHC 801 natural gamma coal thickness indication system.*

*Figure 5*



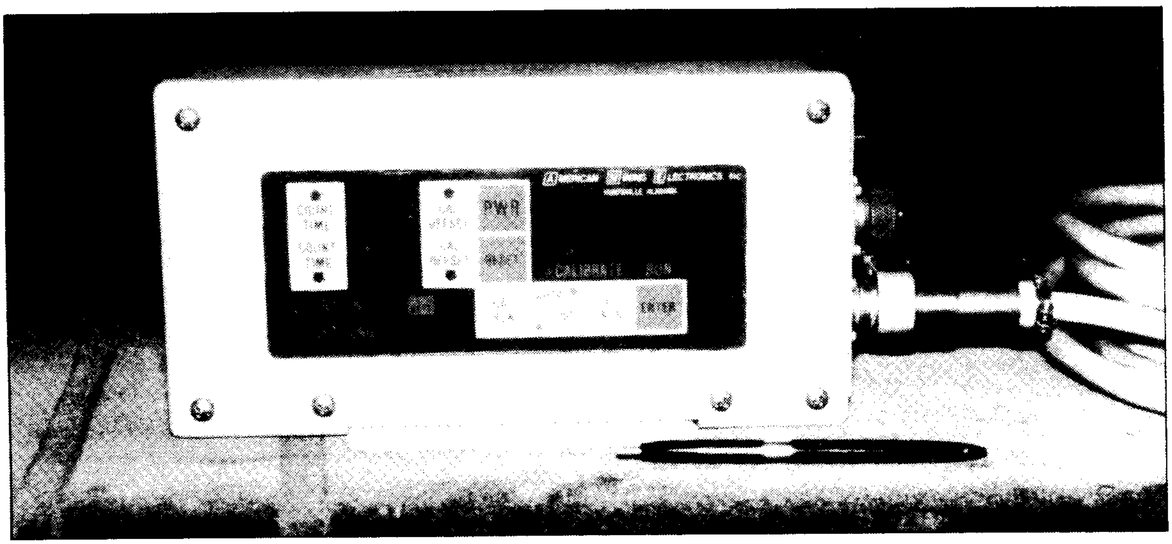

***Physical size comparison between (A) RHC 803 and (B) RHC 801 natural gamma coal thickness indication systems.***

*Figure 6*



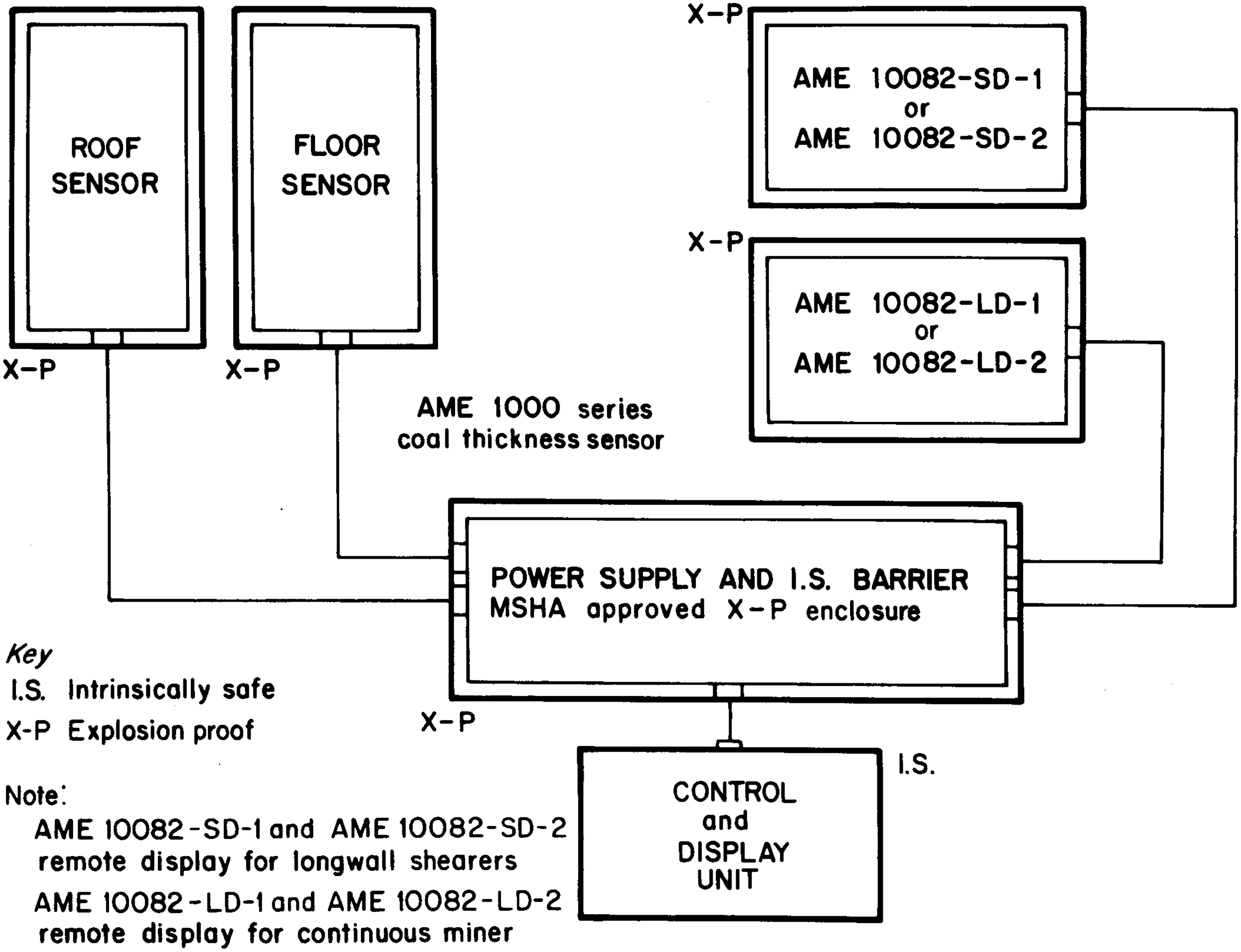
*Gamma sensor for AME 1008 coal thickness measurement system.*

*Figure 7*



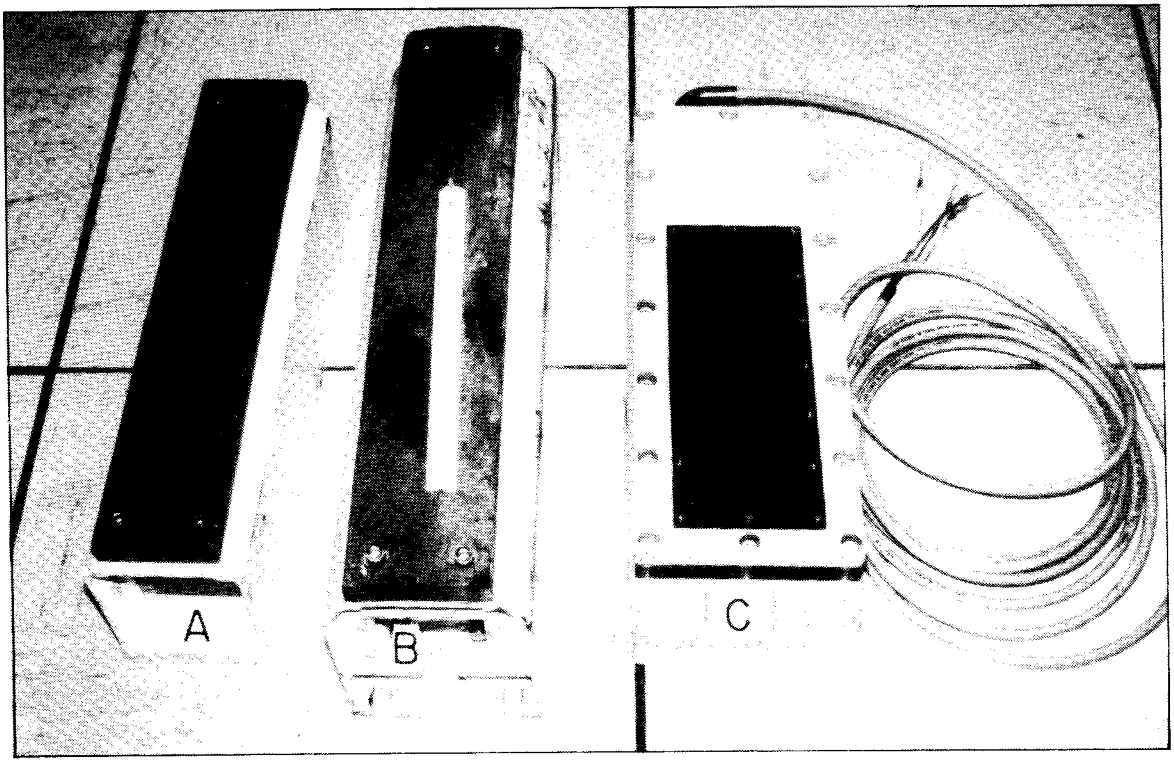

*Operator control and display unit for AME 1008 system.*

*Figure 8*



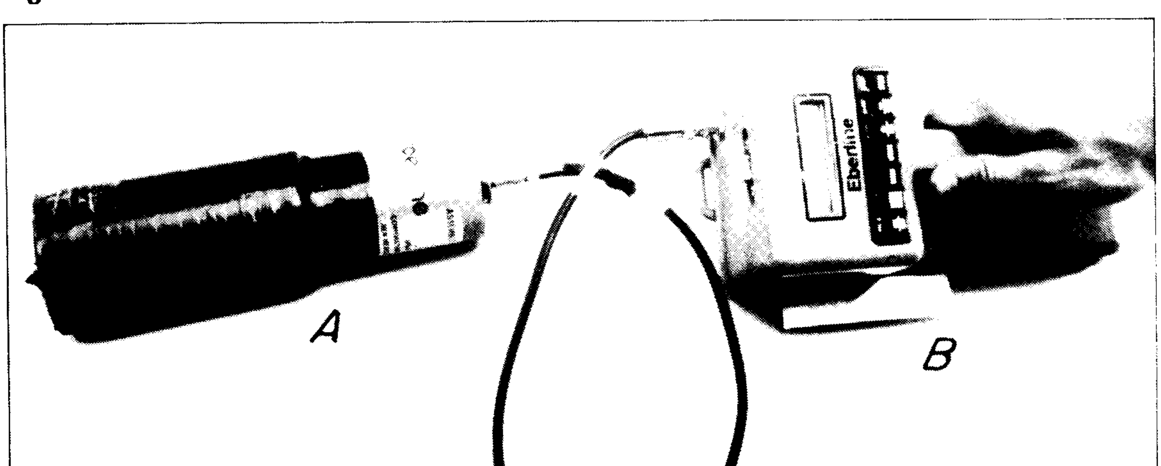

***Block diagram for AME 1008 coal thickness sensor and display system.***

*Figure 9*



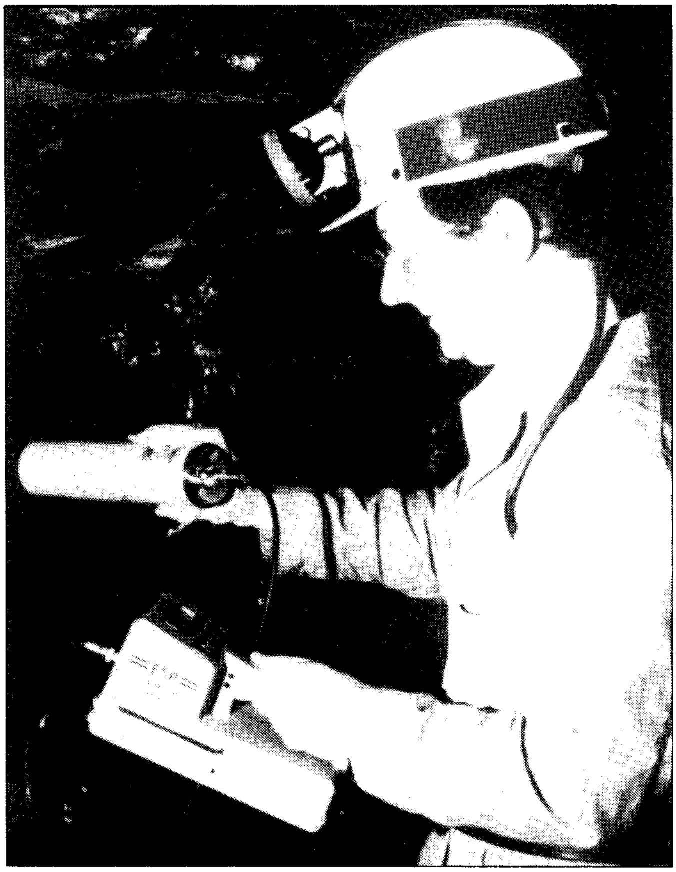

*Physical size comparison between the (A) RHC 803, (B) RHC 801, and (C) AME 1008 natural gamma sensors.*

*Figure 10*



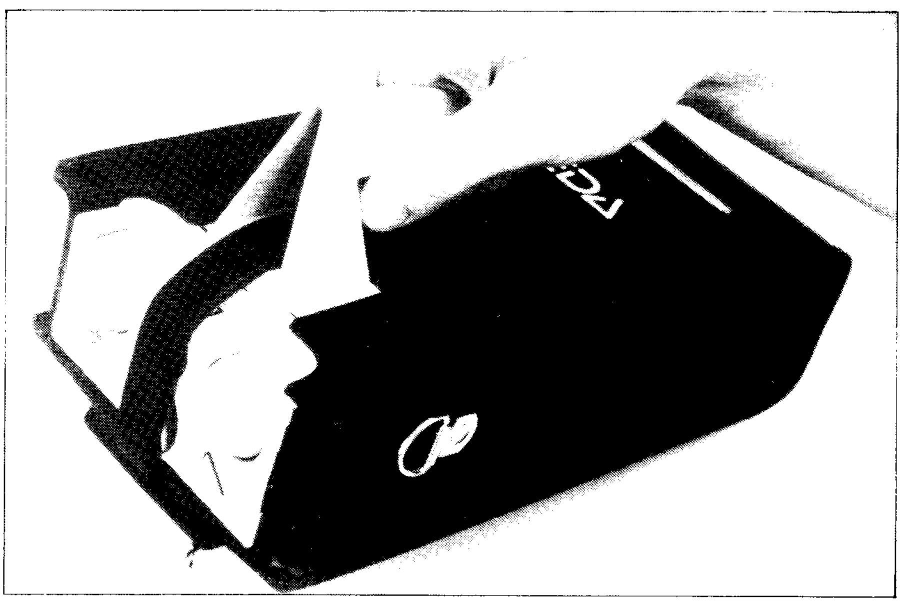

*Eberline ESP-2 unit. (A) Sensor with lead shield; (B) Readout unit.*

*Figure 11*



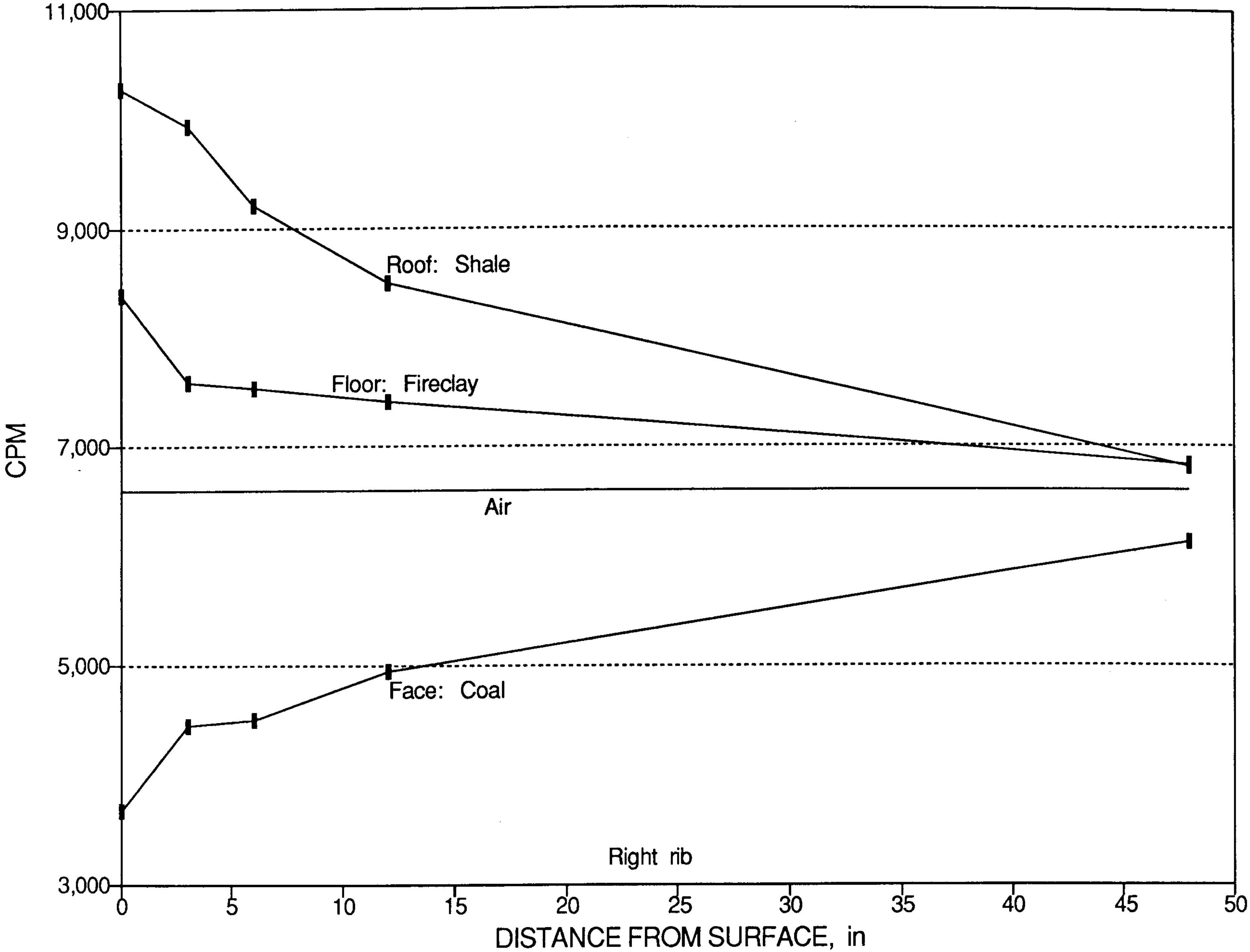
*Eberline ESP-2 being used underground.*

*Figure 12*



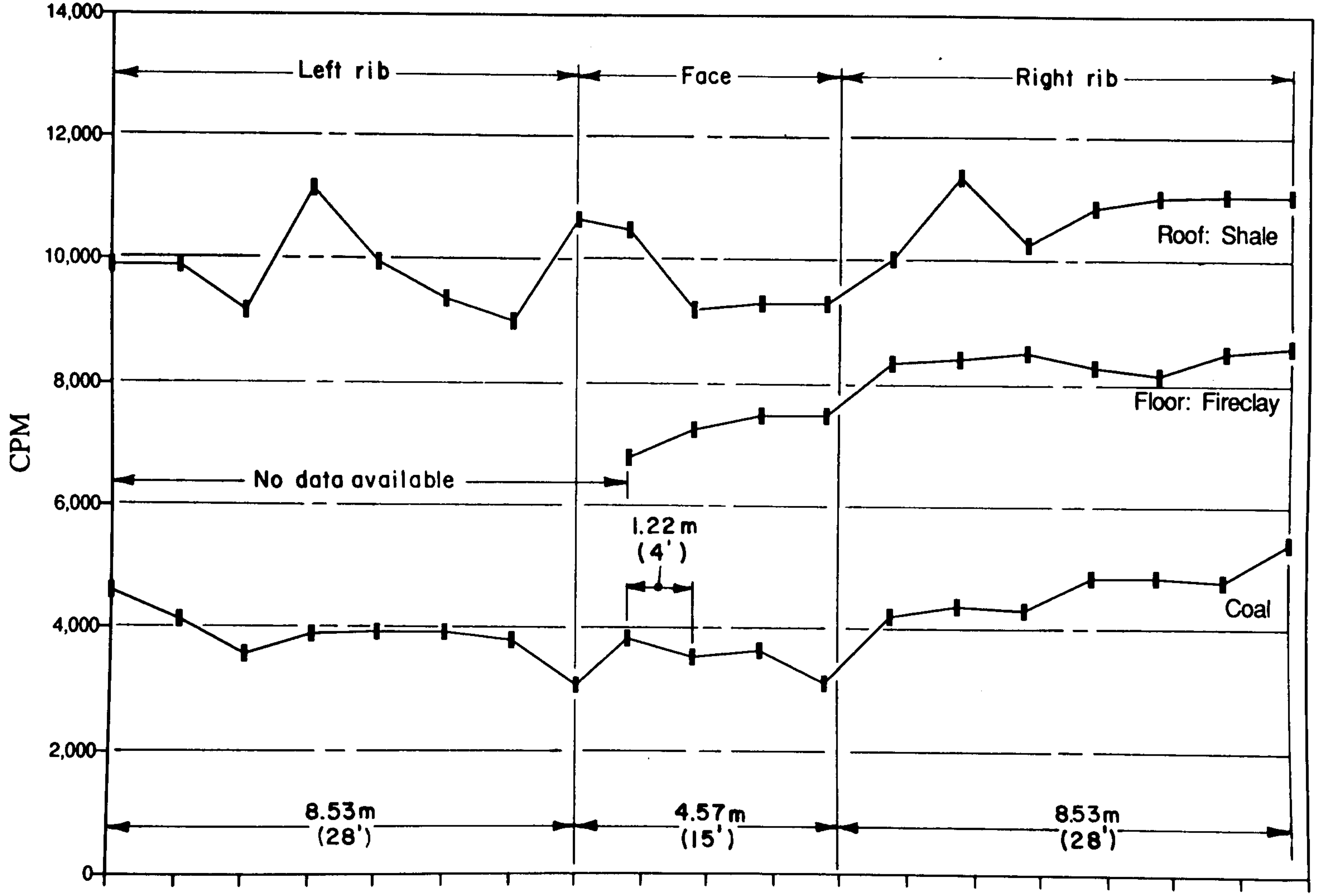
*EDA GRS-500 unit.*

*Figure 13*



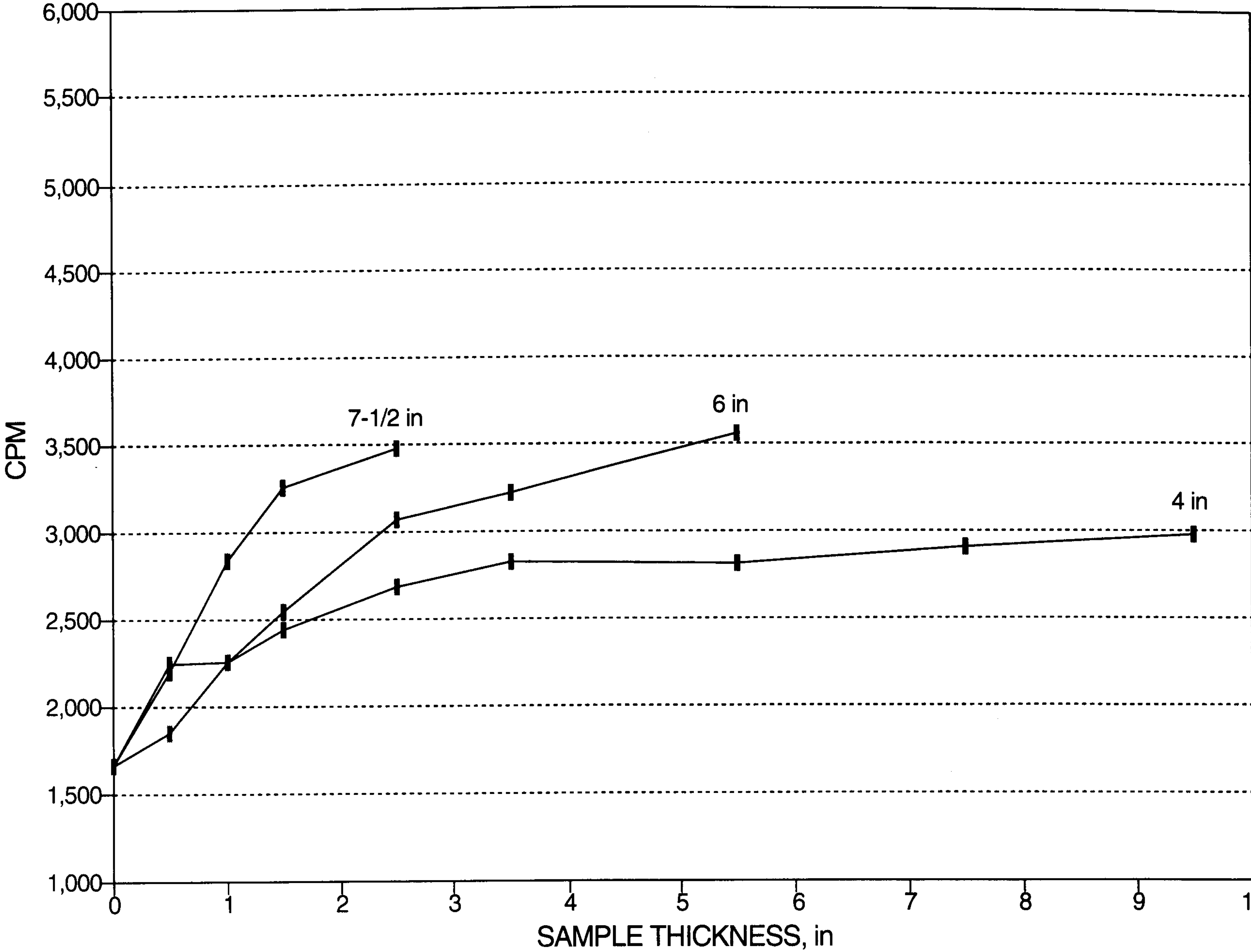

***Effect of NGR rates as a function of distance from a geological surface as measured underground, Pittsburgh Coal Seam.***

Figure 14



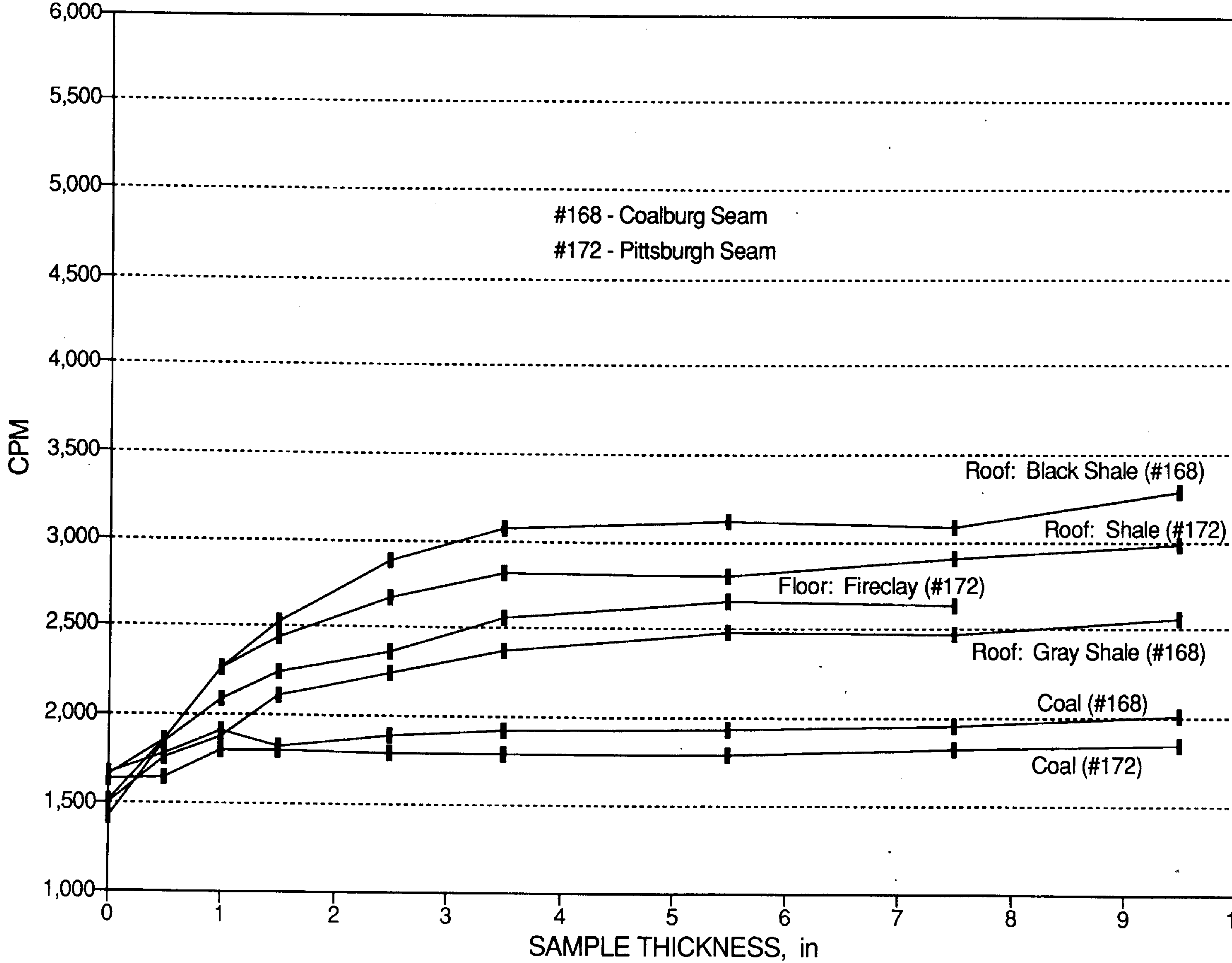

*Variation of NGR rates as measured along an underground coal face and adjacent ribs, Pittsburgh Coal Seam.*

*Figure 15*



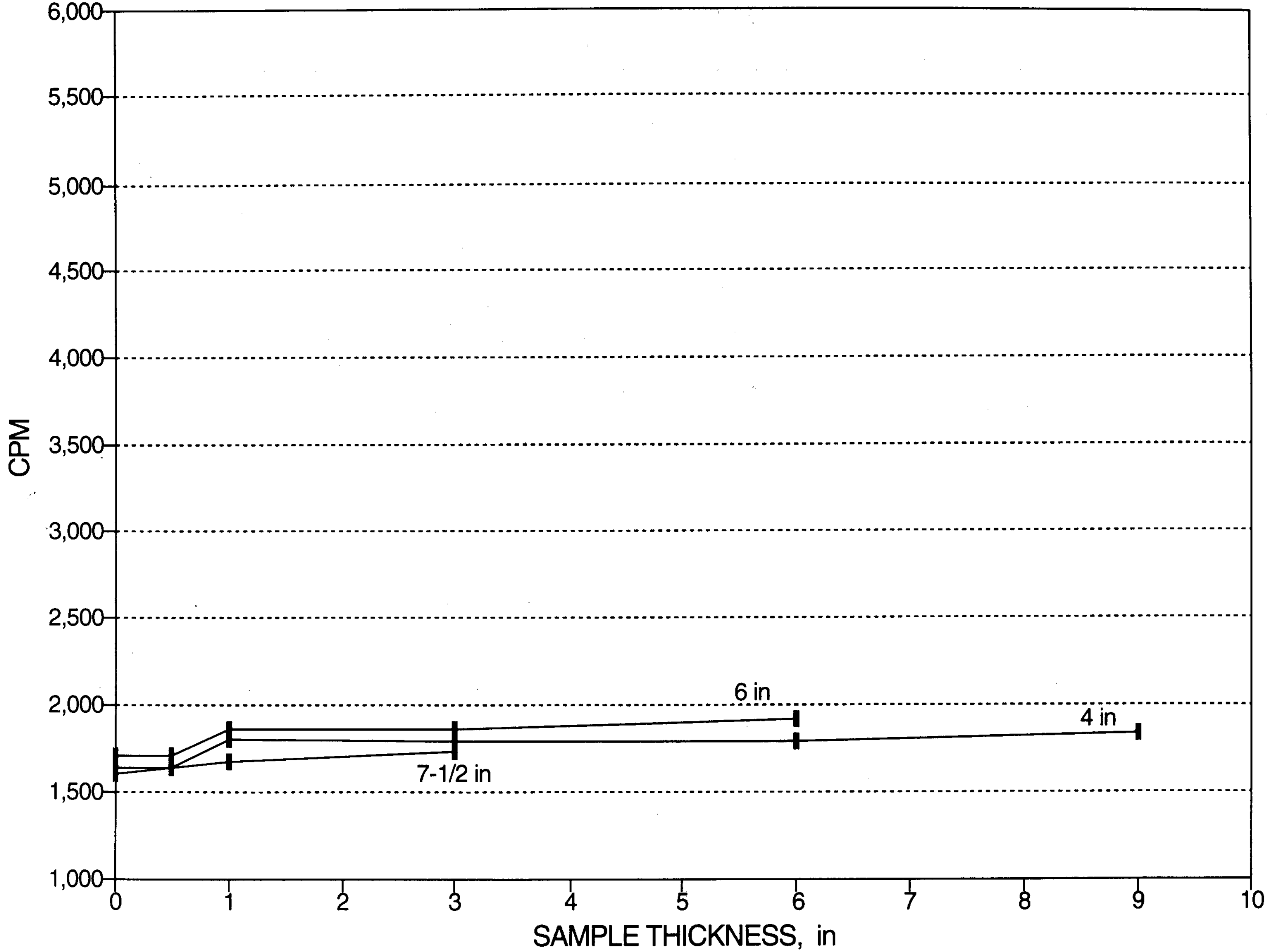

***Effect of roof shale sample thickness on NGR count rate for different container diameters, Pittsburgh Coal Seam—laboratory tests.***

*Figure 16*



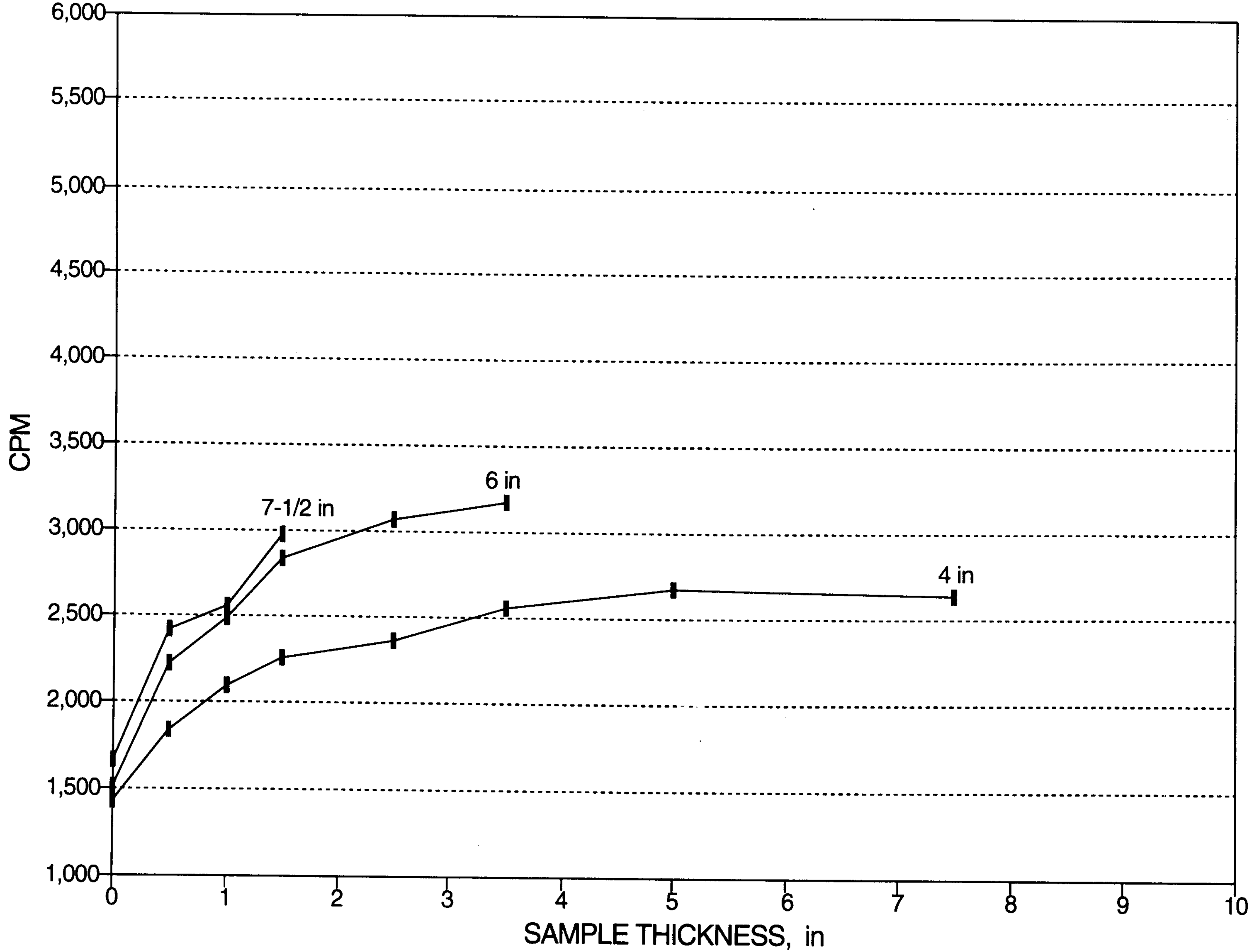

***Effect of sample thickness on NGR count rate for 102-mm (4-in)-diameter container, Pittsburgh and Coalburg Coal Seams—laboratory tests.***

*Figure 17*



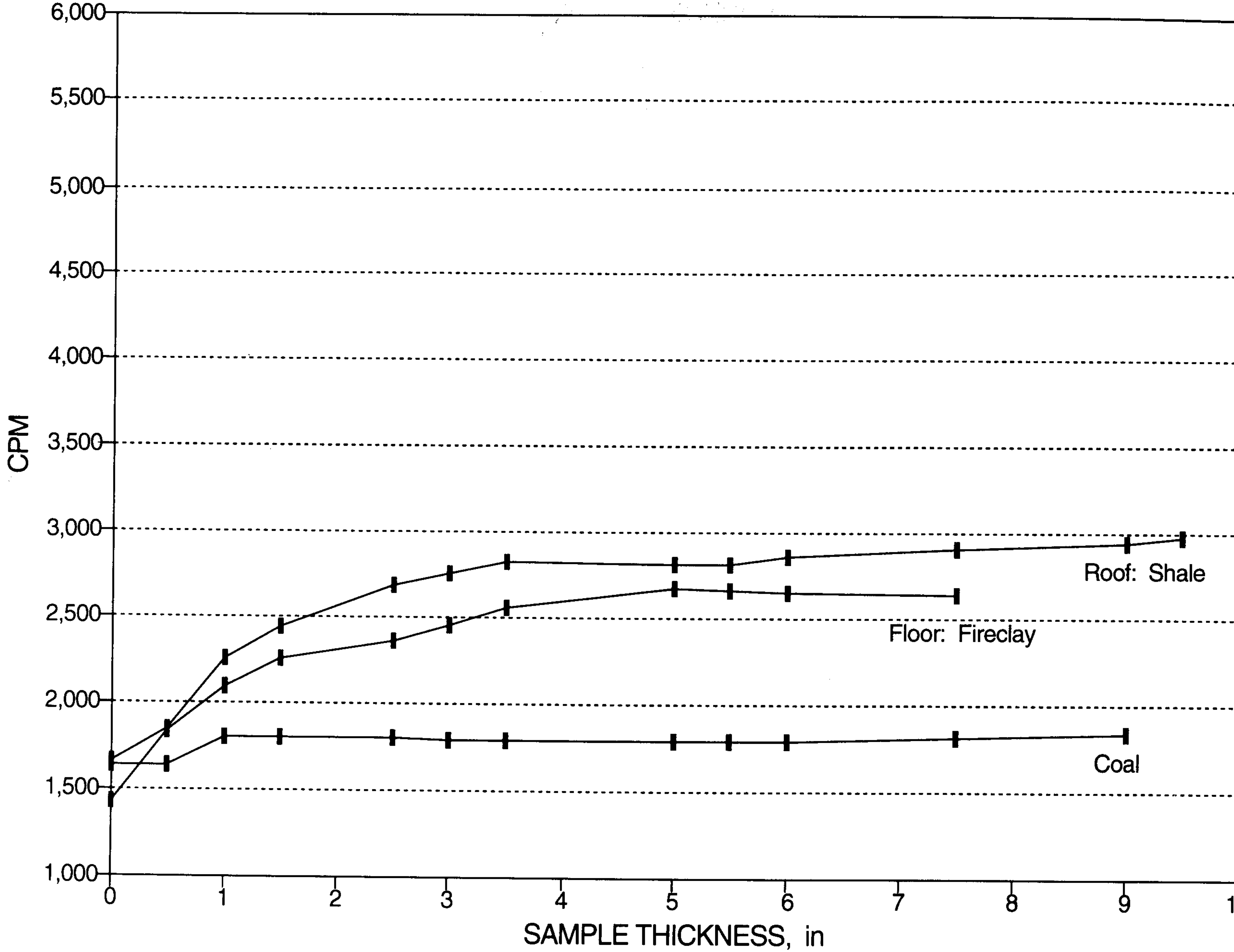

***Effect of coal sample thickness on NGR count rates for different container diameters, Pittsburgh Coal Seam—laboratory tests.***

*Figure 18*



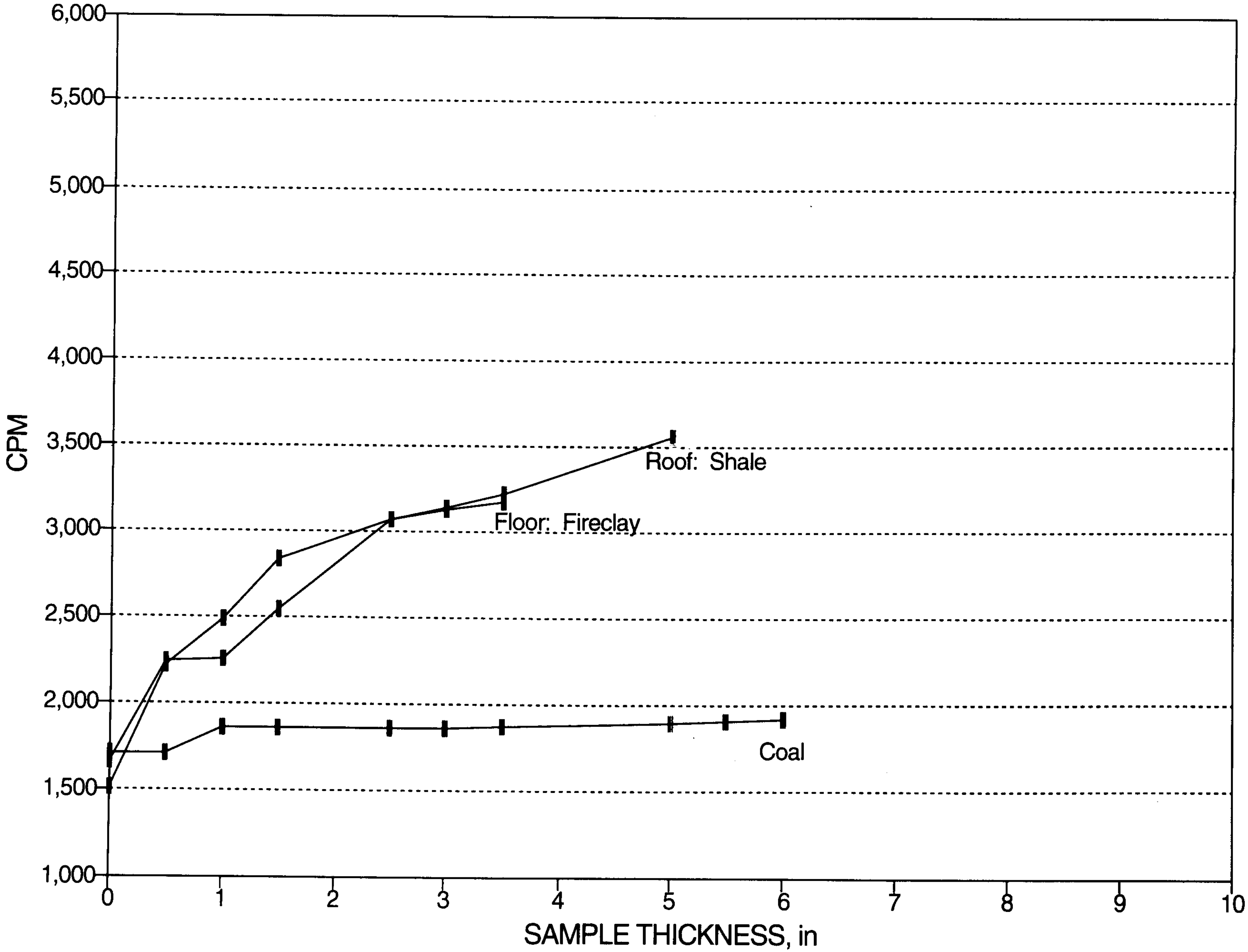

***Effect of floor fireclay sample thickness on NGR count rates for different container diameters, Pittsburgh Coal Seam—laboratory tests.***

Figure 19



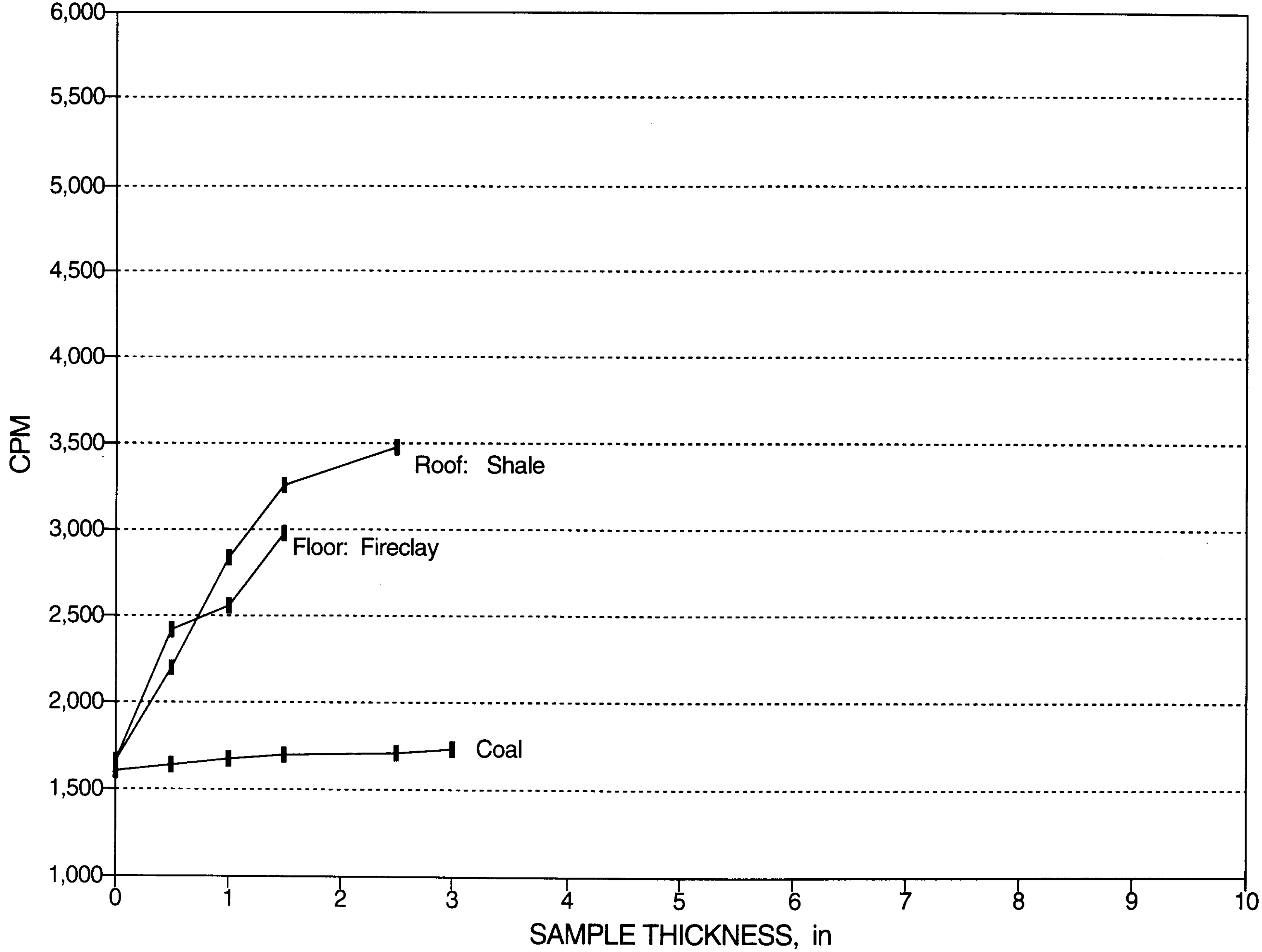

*Effect of sample thickness on NGR count rates for shale, coal, and fireclay, 102-mm (4-in) container, Pittsburgh Coal Seam—laboratory tests.*

*Figure 20*



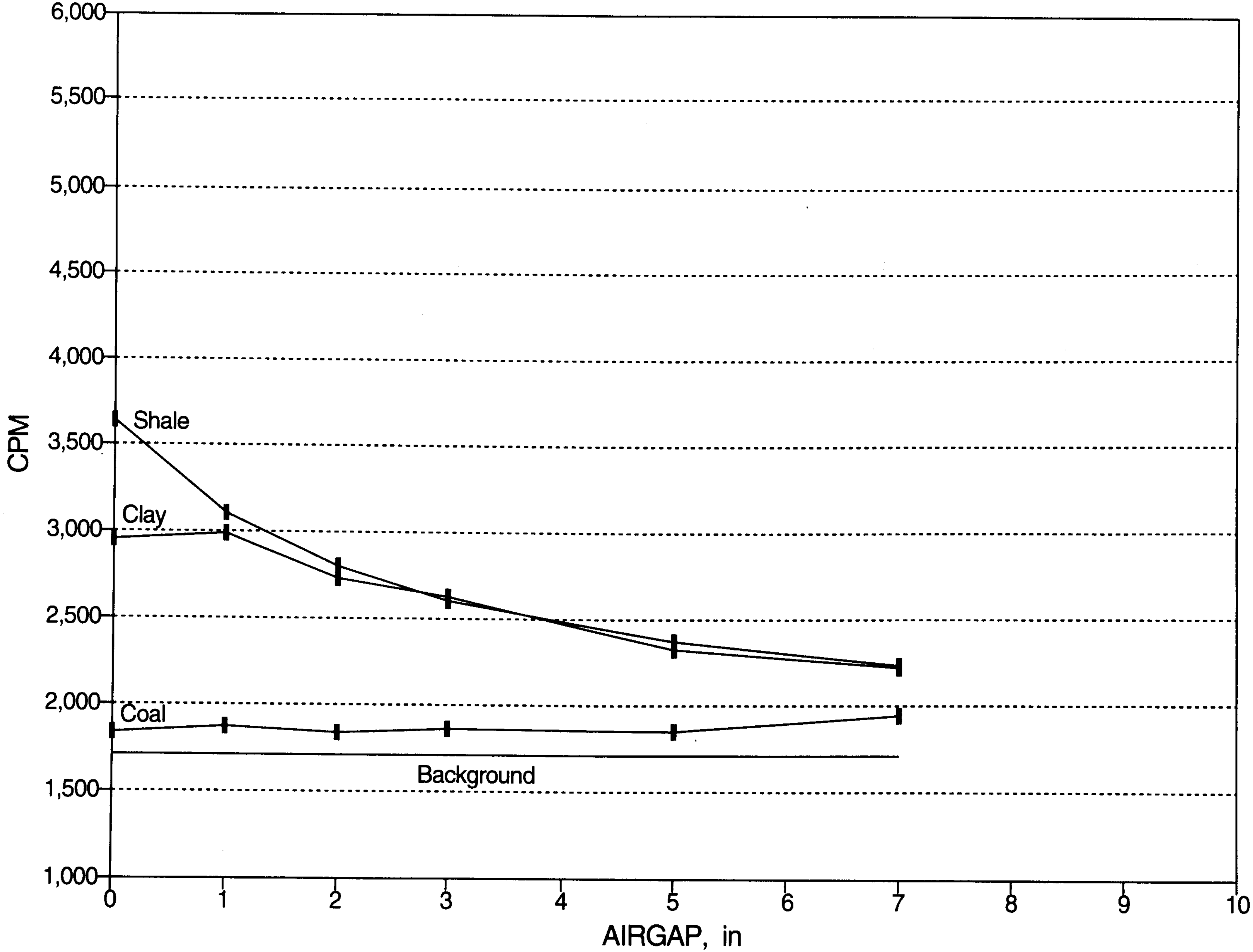

***Effect of sample thickness on NGR count rates for shale, coal, and fireclay, 152-mm (6-in) container, Pittsburgh Coal Seam—laboratory tests.***

*Figure 21*



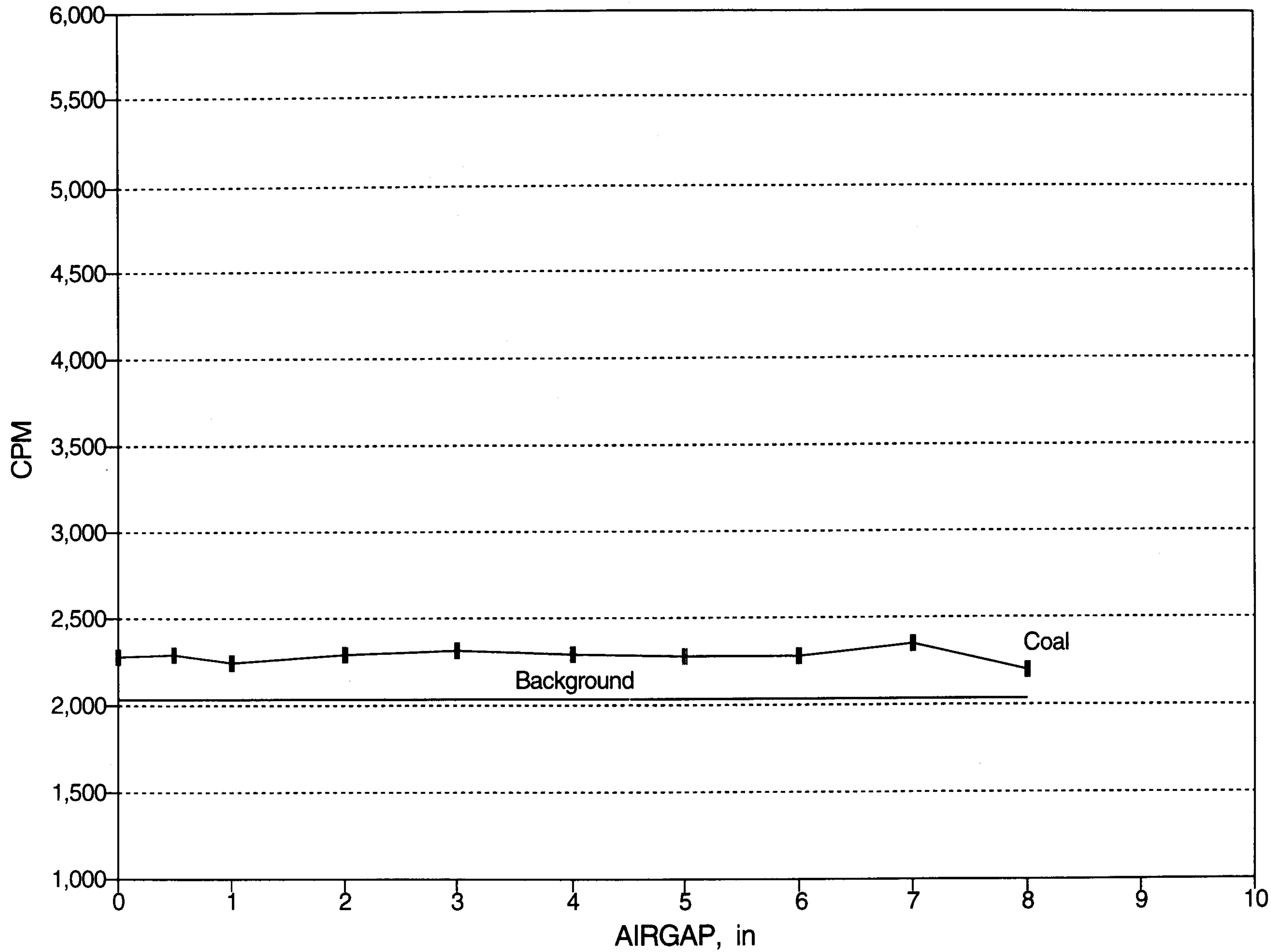

***Effect of sample thickness on NGR count rates for shale, coal, and fireclay, 190.5-mm (7.5-in) container, Pittsburgh Coal Seam—laboratory tests.***

*Figure 22*



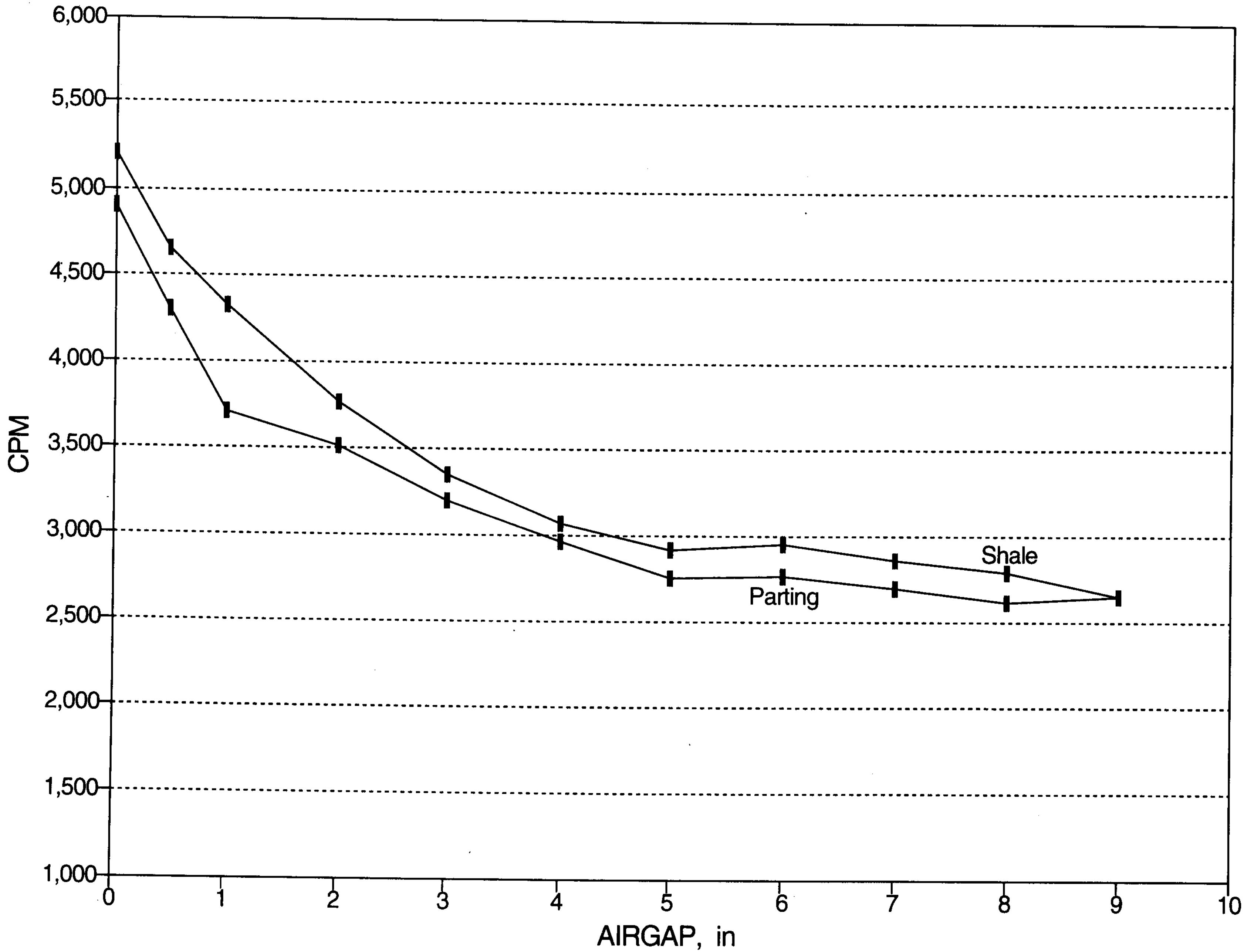

***Effect of airgap on NGR count rates, 203- by 203-mm (8- x 8-in) container, sample thickness = 76 mm (3 in), Pittsburgh Coal Seam—laboratory tests.***

*Figure 23*



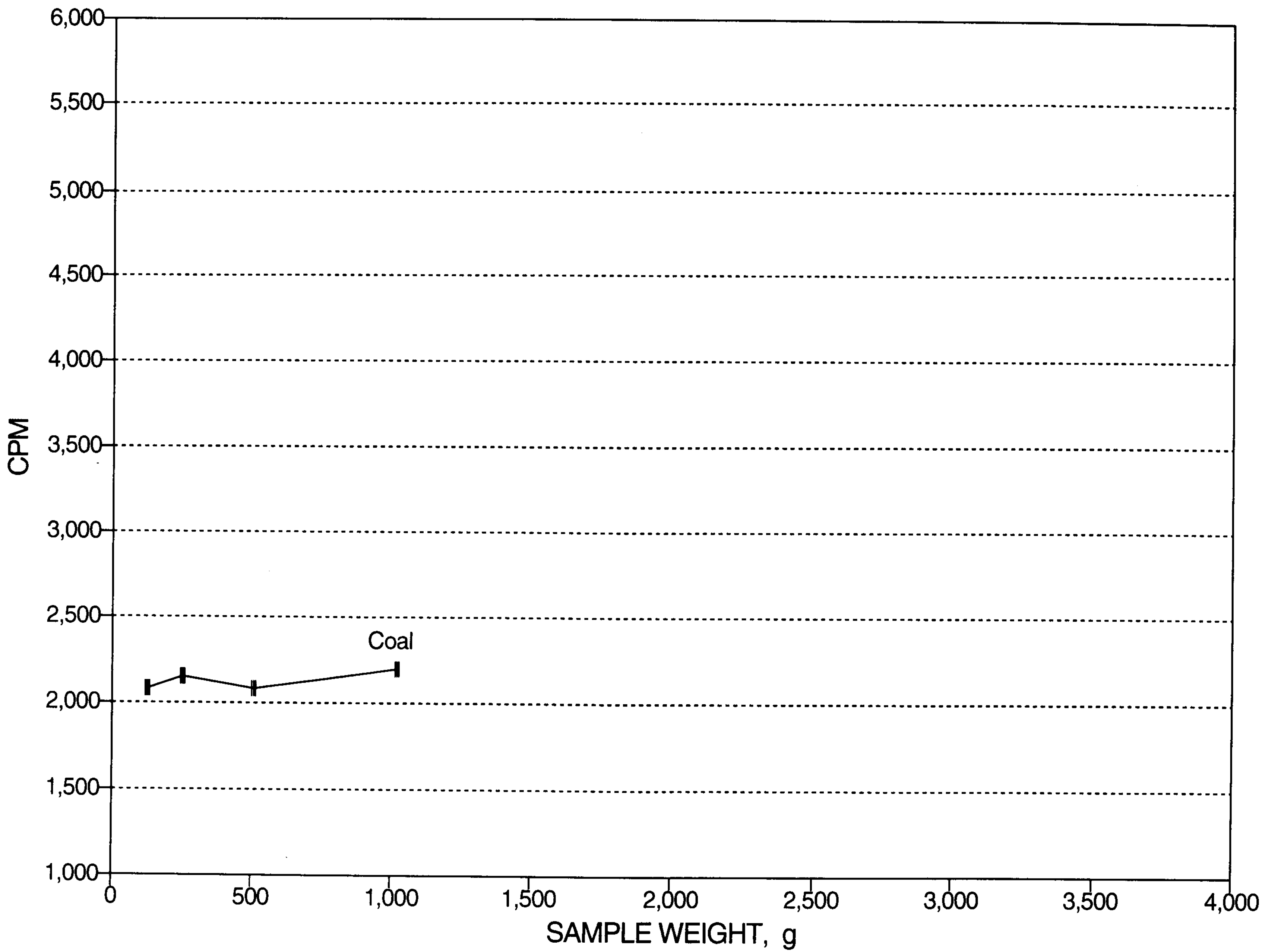

***Effect of airgap on NGR count rates for coal, Pittsburgh Coal Seam—laboratory tests.***

*Figure 24*



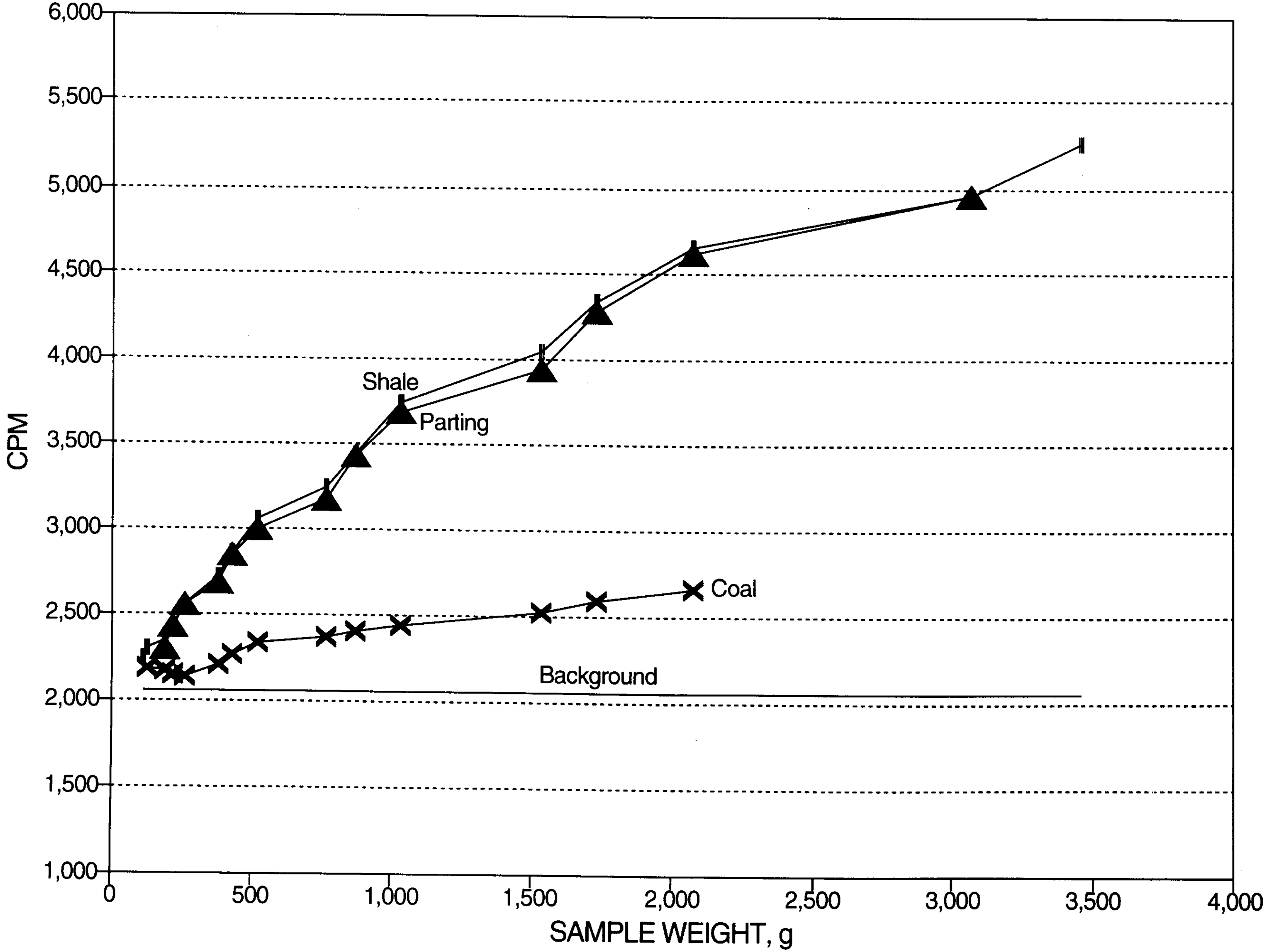

***Effect of airgap on NGR count rates for shale and parting, Pocahontas Coal Seam—laboratory tests.***

*Figure 25*



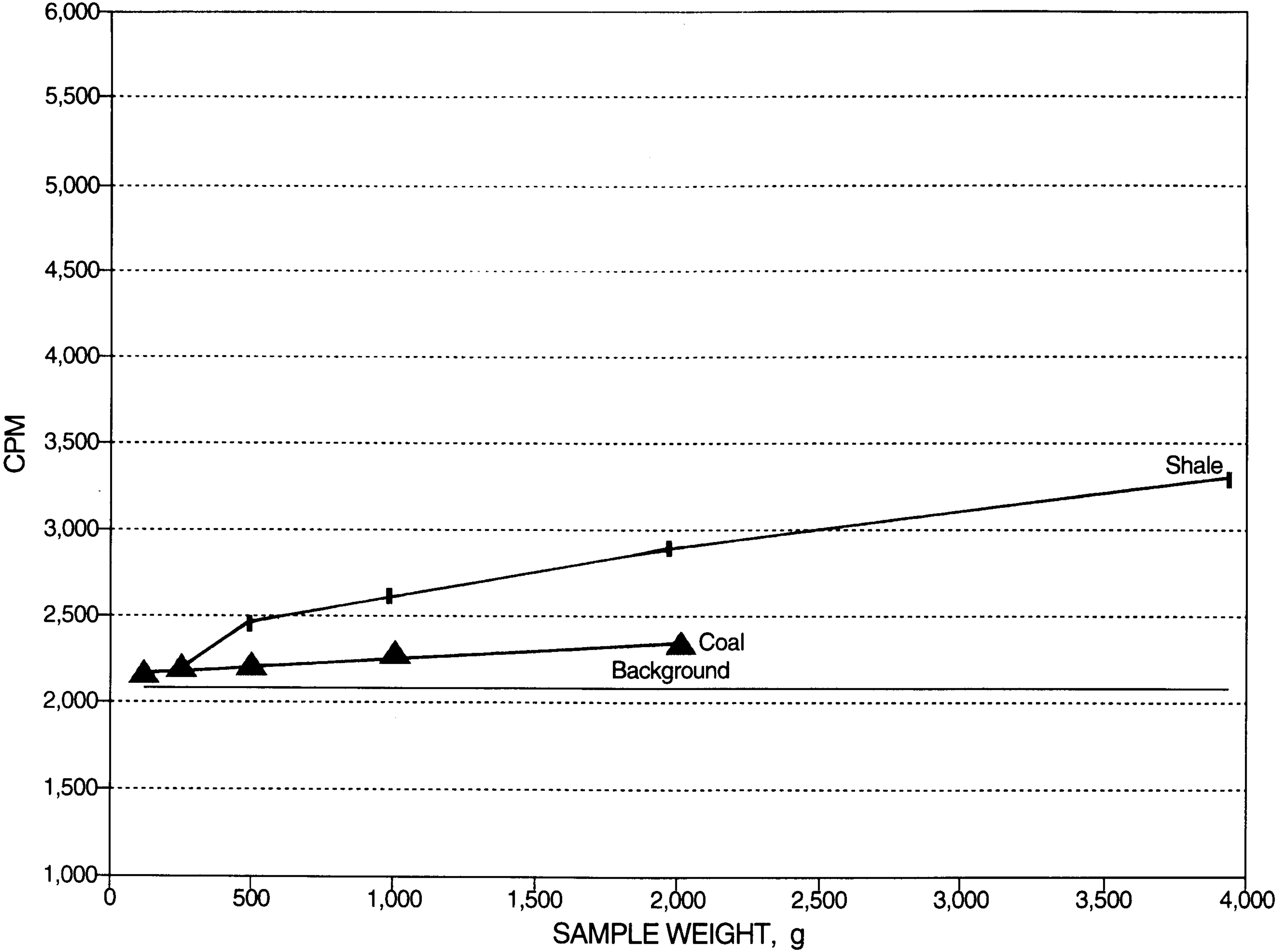

***Effect of coal sample weight on NGR count rates, Pittsburgh Coal Seam—laboratory tests.***

*Figure 26*




***Effect of shale, parting, and coal sample weights on NGR count rates, Pocahontas Coal Seam—laboratory tests.***

*Figure 27*




***Effect of shale and coal sample weight on NGR count rates, No. 2 Gas Coal Seam—laboratory tests.***

# APPENDIX.-TECHNICAL SPECIFICATIONS OF SEVERAL NGR SYSTEMS

## RHC MODEL 801

The RHC Model 801 unit is comprised of three major items and associated cables:

801 NGR Sensor

The 801 NGR sensor (probe) is ruggedly built and can be mounted on the face side of any type of coal-cutting machine. Depending on where it is mounted, the sensor measures the thickness of the coal in the present cut, previous cut, or prior to cutting (on continuous surface miners). It can reliably sense between 0 and 500 mm (0 and 19.5 in) of coal thickness and is capable of accommodating machine speeds of up to 16.8 m/mm (55 ft/min) at 254 mm (10 in) coal thickness.

The probe gives a pulsed digital output. The electronic assemblies that produce the output are mounted in a high 'g' mount and wholly encased in a robust steel case with a window in its top surface. This window is the entry port for the gamma radiation. Strategically placed 12.5-mm (0.5-in) thick lead shielding inside the sensor casing prevents radiation entering by any other way than the window. The overall dimensions of the sensor are 640 mm long by 220 mm high by 170 mm wide (approximately 25 by 8.5 by 6.5 in) and weighs 52 kg (114.4 lbs). The electronic assemblies are a scintillator unit and reforming circuit (figure 1).[1]

The assembly consists of the following components:

- Scintillator Unit
  This is the NGR detector. It is an integral unit comprised of a 152-mm long by 76-mm ID (6- by 3-in) thallium doped caesium sodide (Nal) crystal coupled to a nine-stage photomultiplier and high-voltage generator. A lead shield 12.5 mm (0.5 in) thick, shields the crystal from all gamma radiation except that coming from the selected area. NGR enters the crystal and strikes an electron of the crystal giving off a flash of light. The light flash is seen by the photomultiplier which produces a voltage at its anode that is proportional to the energy detected by the crystal.
- Photomultiplier
  The photomultiplier requires high voltage (approximately 1,200 V). This is provided by a dc-to-dc converter fed by the 10-V supply. Two-thirds of the power required by the probe is consumed by the high-voltage generator. It converts the light flashing from the caesium sodide crystal to voltage.
- Reforming Circuit
  The reforming circuit receives the pulsed output from the photomultiplier and reforms each pulse to an amplitude of 10 V and a width of I20 **µs.**

[1]Figure numbers refer to illustrations in the main text.

Coal Thickness Indicator Unit

This is a microprocessor-based unit which, when coupled to a RHC 801 probe, provides the machine operator with an indication of the deviation from required roof or floor coal thickness. Its dimensions are 325 mm long by 100 mm wide by 85 mm high (12.8 by 4 by 3.4 in) (figure 2).

The horizon (required coal thickness) can be set anywhere in the range from 0 to 500 mm (0 to 19.5 in), the deviation being indicated by LED's in multiples of 20 mm (0.75 in) up to a maximum of ± 80 mm (3.1 in). Automatic calibration and test facilities are built in. Power requirements are approximately 12.5 to 15 V dc at 140 mA.

The front panel from left to right has:

- a round display panel.
- test points, reset, and calibration control buttons under a hinged security flap.
- two Plessey connectors:
  - top one is connected to 801 sensor.
  - lower one connected to the remote indicator or a data transmission system. A protective blank is supplied to cover the connector when not in use.

Power Supply Units

There are presently three standard types of intrinsically-safe (IS) power supplies. Electrically they are identical, the mechanical arrangement of the components is different to suit the space into which it must lit.

One power supply unit requires either a 440 to 550 or 880 to 1,100-V, 3-phase, ac input. An internal transformer drops the output voltage to 16.5 V, 3-phase, ac.

The power supply unit (powered by 16.5 V, 3 phase, ac) provides hvo isolated 15-V dc outputs rated at 140 mA each.

Remote Indicator (optional)

A remote indicator unit, when connected to the coal thickness indicator unit, will provide a secondary set of LED's indicating any error in coal thickness from the horizon setting. The unit is powered by the coal thickness indicator unit; it is normally used for double-ended longwall shearing machines and can be added to the system, if needed (figure 3).

## RHC MODEL 803

The RHC model 803 is 555 mm long by 190 mm high by 138 mm wide (approximately 22 by 7.5 by 5.5 in) and weighs 43 kg (95 lbs). This unit (figure 5) was developed to fit on smaller equipment such as a continuous miner.

The main difference between the RHC 803 and the original RHC 801 unit is a different method of isolation. In the 801 unit, all the components are held in a cradle that is rubber-isolated. The 803 unit has done away with the suspension, and the basic cradle is covered with a stainless-steel alloy case. Further, the original 801 unit had the ability for an analog and a reverse analog output that were never used. Consequently, one of the circuit boards was removed from the 803 unit. Both models today give only digital outputs.

## AME 1008 AND 1016 UNITS

The AME Model 1008 coal thickness sensor is a high-performance system, containing a large-area gamma detector, which accurately measures coal left on the roof or floor when seam boundary material contains gamma-producing elements.

The sensor assembly, housed in the explosion-proof (X-P) enclosure, has a window to receive "natural background gamma radiation from the rock at the coal seam boundary. When the window is pointed at the roof or floor area to be measured, the total gamma emission entering the window is relative to the thickness of coal left at the rock boundary. The sensor has 305 by 102 by 51 mm (12 by 4 by 2 in) Nal crystal (figure 6). In most applications, the sensor may be placed as much as 0.91 m (3 ft) away from the coal surface.

An IS control and display unit converts gamma counts from the sensor to inches of coal thickness, which are displayed to the operator on the front panel (figure 7). This unit requires a 12-V dc, 500~mA power supply source.

The AME 1008 system measures 25.4 to 406.4 mm (1 to 16 in) of coal, where adequate and consistent natural radiation exists in the seam boundary rock. Figure 8 shows a block diagram and connection schematic of the AME 1008. Measurement accuracy is within ± 6.4 mm (0.25 in) at 152.4 mm (6 in). Other beneficial features are:

- High-sensitivity detector and electronics are mine-permissible and housed in a rugged steel enclosure.
- Sensor can be easily calibrated by an operator on-site; it is simple to operate and requires minimal training. It can be easily installed on mining machine for roof or floor measurements.
- Sensor has ruggedized and moisture-sealed construction, and includes environmentally-sealed cable connectors. It has extensive shielding to block unwanted radiation background count; IS control-display unit-operated microprocessor; and continuous coal thickness readout on a bright LED display.
- Available electrical outputs of the sensors include:
  - coal thickness
  - 0 to 5-v analog
  - gamma counts.
- Ac-dc power supply, which is located in the operator's X-P power box, operates on 100- to 130-V ac power from the mining machine.

| Components supplied | Dimensions (L x W x H) | Weight |
|---|---|---|
| Gamma sensor | 584.2 by 203.2 by 152.4 mm (23 by 8 by 8 in) | 90.72 kg (200 lbs) |
| Control and display unit | 203.2 by 152.4 by 88.9 mm (8 by 8 by 3.5 in) | 4.54 kg (10 lbs) |
| IS barriers | 152.4 by 101.8 by 50.8 mm (8 by 4 by 2 in) | 0.45 kg (1 lb) |
| Ac-dc power supply | 101.8 by 152.4 by 78.2 mm (4 by 6 by 3 in) | 2.27 kg (5 lbs) |
| Connecting cables | Lengths as required | |

The recently developed larger size AME 1016 system measures up to 890 mm (35 in) of coal with sufficient NGR counts. However, this system was not available for evaluation for this report.

## EBERLINE ESP-2 UNIT

The Eberline Smart Portable (ESP-2) radiation survey instrument is designed to be used for routine radiation surveys. The ESP-2 unit may also be used in remote areas, operated solely by a computer. It utilizes a scintillation detector [51-mm long by 51-mm ID (2- by 2-in) Nal crystal] to measure NGR in both field and laboratory. It is also equipped with a single-channel pulse height analyzer (PHA). Information provided by this instrument is used to determine if the NGR technique is potentially applicable in the field at a given mine and seam. Figure 10 shows the Eberline Smart Portable Model ESP-2 Unit.

Specifications

1. Mechanical:
   a. Overall dimensions of this device are 267 mm long by 127 mm high by 132 mm wide (10.5 by 5.0 by 5.2 in).
   b. Weight of the unit (excluding probe) is approximately 1.73 kg (3.8 lb).
2. Temperature:
   a. Operating: -20 °C to +50 °C (-4 °F to 122 °F).
   b. Storage: -30 °C to +80 °C (-22 °F to 176 °F).
3. Voltage:
   a. Low voltage: 5 V dc.
   b. High voltage (detector bias voltage): 500 to 2,450 V dc, adjustable from the keypad.
   c. Battery supply voltage: 5.8 to 10.0 V dc.
4. Detectors:
   The detectors connect to the ESP-2 unit via a coaxial connector located on the front of the instrument.
5. Readout:
   a. Two lines of 16 alphanumeric characters are presented on liquid crystal display (LCD).
   b. Character size: H = 4.45 mm (0.175 in); W = 3.15 mm (0.124 in).
   c. Bar graph resolution: 1 in 48 (2.1%).
6. Power Supply:
   The ESP-2 unit uses six C-cell batteries. Six alkaline batteries provide approximately 300 h of continuous use. The ESP-2 senses the low battery condition at 0.95 V dc/cell and signals the user by blinking the first character on the display.

## EDA GRS-500 SYSTEM

The GRS-500 Differential Gamma Ray Spectrometer/Scintillometer is manufactured by EDA Instruments Inc., Toronto, Canada. This instrument is a compact portable field spectrometer with simplified operational controls. It has two spectrometers that are used to measure the gamma radiation emitted by various daughter isotopes in the uranium decay series. The first of these is a sensitive wide-energy-band spectrometer used for general reconnaissance. This is a sensitive scintillometer, or more correctly, a broadband spectrometer. This is a simple instrument which measures total gamma ray activity from the uranium series, as well as emitters from the naturally occurring potassium and thorium series.

The second instrument is an accurately-calibrated, stable, sensitive spectrometer that detects gamma radiation originating from certain discrete isotopes. These include Bismuth-214, Thallium-208 and Potassium40 isotopes with well-defined energy peaks from the uranium, thorium, and potassium series, respectively. The GRS-500 is a lightweight 5-channel spectrometer (figure 12).

This instrument combines the functions of both spectrometers and serves in a variety of functions including:

- Rapid reconnaissance surveying.
- Ground follow-up of airborne anomalies.
- Detailed radio activity analysis of uranium, thorium, and potassium.
- Detection of radioactive glacial float and detritus.
- Lithological and structural mapping.
- Systematic surveys and property evaluation.
- Qualitative screening of drill core, chip samples, and slurry.

Specifications

Detector-Nal(Tl) crystal and high-stability photomultiplier tube with a mu-metal magnet shield. The detector volume is 124 $cm^3$ (75 $in^3$). Mechanically ruggedized.

Energy Thresholds—Switch--selectable to:

TC1 • Total count above 0.08 MeV.
TC2 • Total count above 0.40 MeV.
K • All gamma energies between 1.35 and 159 MeV.

U • All gamma energies between 1.65 and 1.87 MeV.

T • All gamma energies above 2.45 and 2.79 MeV.

Display-5-digit ruggedized low-temperature LCD. Displayed counts normalized to count per second. Flashing count overflow and battery charge status indicators custom designed into display.

Sample Rate-l.0 or 10.0 s, auto recycle, for all energy levels, except for "CAL" position.

CalibrationSource-Barium-133 ($^{133}Ba$) Isotope. Rated activity 05 µCi.

Power-Four alkaline "C" cells with an average continuous operation of 60 h without audio at 23 °C ambient temperature.

Operating Temperature- -10 °C to +60 °C (+ 14 °F to + 140 °F).

Relative Humidity-O to 100%.

Weight-2.3 kg (5.0 lb).

Dimensions-235 by h by 64 mm (9.25 by 4.5 by 2.5 in).

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