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**Radiological Survey of the
Inactive Uranium-Mill
Tailings at Maybell, Colorado**

F. F. Haywood
P. T. Perdue
B. S. Ellis

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ORNL-5456
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Contract No. W-7405-eng-26
Health and Safety Research Division

**RADIOLOGICAL SURVEY OF THE INACTIVE URANIUM-MILL
TAILINGS AT MAYBELL, COLORADO**

F. F. Haywood, P. T. Perdue, and B. S. Ellis

Date Published: March 1980

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RADIOLOGICAL SURVEY OF THE INACTIVE URANIUM-MILL
TAILINGS AT MAYBELL, COLORADO

F. F. Haywood, P. T. Perdue, and B. S. Ellis

ABSTRACT

Results of a radiological survey of the inactive uranium-mill tailings near Maybell, Colorado are presented. Measurements of external gamma exposure rate at 1 m above the tailings ranged 16 to 340 $\mu\text{R/hr}$ with an average value of 65 $\mu\text{R/hr}$. Radionuclide analysis of offsite soil and sediment samples, as well as above-ground gamma exposure rate measurements defined the spread of contamination around the tailings pile. This spread is greatest toward the east, in the direction of surface water runoff. Calculated concentrations of ^{226}Ra in all of the holes drilled in the tailings, based on gamma monitoring data, showed maximum concentrations in the range 100 to 800 pCi/g.

1. INTRODUCTION

This is one of a series of reports on results of radiological surveys of uranium-mill tailings at inactive mill sites in western United States. A list of all the reports in this series is found at the front of this report. The first four reports include attempts to assess potential health effects of radiation and radionuclides from the sites. The first report (Salt Lake City) also contains a discussion of modes of radiation exposure to individuals and to population groups resulting from the radionuclides in tailings at uranium-mill sites and a survey of the pertinent literature. This report on the inactive mill site near Maybell, Colorado, presents the results of a radiological survey conducted in May 1976 together with descriptions of the apparatus and techniques used to obtain the data. The survey was conducted in cooperation with an engineering team from Ford, Bacon and Davis Utah Inc., the architect-engineering company responsible for the Phase II engineering assessment of the sites considered in this series. Their report on this site has been published.¹ Results of a gamma radiation survey of these sites [by the Environmental Protection Agency (EPA)] have also been published.² The previously unpublished Phase I report on the visit to the Maybell site by Mayer et al. is included in Appendix I. Several publications³⁻⁸ include discussions of the uranium-mill tailings problem and of the assessment of their radiological impact.

2. SITE DESCRIPTION

A description of the inactive uranium-mill site near Maybell, Colorado and a history of the operations at this site are included in the Phase I engineering report (Appendix I). Only a brief summary of this information is presented here.

The Maybell site, owned by Union Carbide Corporation, is located 9 km northeast of the town of Maybell. An aerial photograph of the site and surrounding area is shown in Fig. 1. The tailings pile covers an area of approximately 28.3 hectares (70 acres) (Appendix I) or an area

ORNL Photo 0533-79

Fig. 1. Aerial photograph of the Maybell site. Source: EG&G, Inc.

of 32.4 hectares (80 acres),¹ while the mill site covers an area of 1.6 hectares (4 acres).¹ Operation of the uranium mill lasted for seven years, and production of uranium concentrate ceased in November 1964. During this time, approximately 2.4 million metric tons of ore containing an average U_3O_8 content of 0.098% was processed. This ore was taken from nearby strip mines. Piles of overburden and low-grade-ore stock piles are reported in the vicinity. The tailings pile was estimated (Appendix I) to have a theoretical concentration of ^{226}Ra of 270 pCi/g and contains a total of 640 Ci of this isotope.

All mill buildings at this site were removed after mill operations ceased, but some of the building foundations remain. The tailings pile was graded and covered to an average depth of approximately 15 cm with soil in accordance with Colorado regulations, and a program of revegetation was instituted. About 40% of the tailings was reported¹ to be covered with vegetation, but there has been evidence of wind and water erosion.¹ The entire tailings area is fenced, with locked gates, and posted with warning signs (Appendix I). However, grazing of cattle within the fenced area was observed by the authors during the survey.

Some heap leaching of low-grade ore was reported¹ to have been performed at this site by Union Carbide Corporation subsequent to the survey reported here.

3. SAMPLING TECHNIQUES AND RADIOLOGICAL MEASUREMENTS

Sampling techniques as well as equipment and methods used for radionuclide analyses of soil samples and radiological monitoring are described in Appendix II, and a description of the techniques used to analyze water samples is contained in Appendix III.

4. EXPERIMENTAL RESULTS

Measurements were made at the Maybell site to determine: (1) background radiation levels and radionuclide concentrations in area soil samples; (2) external gamma exposure rates 1 m above the ground at the

site; (3) the radionuclide concentration in surface or near-surface soil samples; (4) the concentration of radionuclides in water samples; and (5) the distribution of ^{226}Ra in tailings piles and other contaminated areas as a function of depth. The concentration of radon, radon daughters, or other airborne particulate matter was not measured at this site due to limitations in time and absence of buildings. Results of the various types of measurements are discussed in separate parts of this section below.

4.1 Background Radioactivity

Knowledge of background external gamma radiation levels and of background concentrations of radionuclides in the area surface soil is needed in order to evaluate the extent of spread of tailings from the site and to provide data needed in implementing clean-up procedures.

Locations where background measurements were made of external gamma-ray exposure rates 1 m above the ground and where surface soil samples were obtained for radionuclide analysis are shown in Fig. 2. Details of the sample sites and the results obtained are displayed in Table 1.

The data in Table 1 show a variation in measured values of the background gamma exposure rate 1 m above the ground from 10 to 17 $\mu\text{R/hr}$. The average value of 13 $\mu\text{R/hr}$ corresponds to an annual background dose equivalent of 114 millirems. The average ^{226}Ra concentration in surface soil is 1.3 pCi/g. There is not a good correlation between the direct gamma exposure rate and the ^{226}Ra concentration in surface soil, possibly due to the presence of other terrestrial radionuclides, failure to obtain representative soil samples, and poor statistics due to the small quantity of activity present.

Fig. 2. Locations of background external gamma measurements and background surface soil samples.

Table 1. Background radiation level and concentration of radionuclides in surface soil near Maybell, Colorado

Sample point	Description of sample location	External γ exposure rate ^a (μ R/hr)	Nuclide concentration (pCi/g)		
			²²⁶ Ra	²³² Th	²³⁸ U
C020	W side of Hwy 139 past the crest of Douglas Pass going N	17	2.2	1.2	0.8
C021	End of Colorado State Rt 330 at Collbran, on SW corner of intersection with road to Grand Mesa	10	1.9	1.1	0.8
C022	DeBeque at the intersection of county road and routes 6 and 24	11	1.5	2.1	0.6
C023	19 km (12 miles) SE of Glenwood Springs, on the NE side of Hwy 82, edge of orchard	15	1.2	^b	0.4
C024	Right side of Hwy 40, 3.2 km (2 miles) W of Lay post office, 12 m from road	11	1.4	1.1	0.4
C025	Intersection of Moffitt County dirt roads 17 and 119 in Yampa River Valley	12	0.7	0.8	0.3
C026	S side of US 40 east of Maybell	^b	0.5	0.6	0.2
Average		15	1.3	1.2	0.5

^aOne meter above the ground.

^bThis nuclide not sought.

4.2 Direct Gamma-Ray Exposure Rates

Measurements were made of direct gamma-ray exposure rates 1 m above the ground using the "Phil" gamma-ray dosimeter described in Appendix II. These measurements were made at 46-m (50-yd) intervals. The data (Fig. 3) show exposure rates over the tailings pile ranging from 16 to 338 $\mu\text{R/hr}$ with an average value of 65 $\mu\text{R/hr}$. These data show that spread of tailings from the Maybell site has occurred toward the east and toward the northwest. Only in the latter direction were measurements taken far enough to reach the background level (13 $\mu\text{R/hr}$). The gamma survey by Douglas and Hans² also provided an indication of the extent of area contamination.

4.3 Concentration of ^{226}Ra in Surface Soil and Sediment Samples

Analyses of soil and sediment samples for ^{226}Ra and its daughters supplements the measurements of above-ground gamma exposure rate in detecting the spread of uranium tailings or uranium-ore particles. Surface and near-surface soil and sediment samples were analyzed for ^{226}Ra by use of the technique and equipment described in Appendix II. Soil sample locations and results are shown in Table 2.

It may be concluded from the data in Table 2 that surface contamination with ^{226}Ra was widespread in the vicinity of the Maybell tailings pile, but not enough samples were obtained to define accurately the extent of area contamination. Movement of tailings by water erosion appears to have proceeded as far as Lay Creek, an intermittent stream that is a tributary of the Yampa River. The data in Table 2 show no evidence that tailings particles have reached the Yampa River. It was reported¹ that wind and water erosion of tailings from the eastern slope of the pile has occurred. The data in Table 2 help to define the extent of water erosion in the eastern direction from the tailings pile, but the gamma measurements in Fig. 3 probably better serve the purpose of showing wind dispersion of tailings particles.

ORNL Photo 2161-79

Fig. 3. Measurements of external gamma exposure rates 1 m above the ground. Original photo by EG&G, Inc.

Table 2. Concentration of ^{226}Ra in surface soil and sediment samples at the Maybell site

Sample designation	Sample location and description	Concentration of ^{226}Ra (pCi/g)
MCWS1	Sediment in water from SE bank of stream at bridge that parallels Hwy 40 ~0.4 km (0.25 mile) from east entrance to mill site on Hwy 40	1.2
MCWS2	Sediment in water from same stream as WS1 ~2.4 km (1.5 mile) from the point where Johnson Wash empties into stream	2.9
MCWS3	Sediment in water from ~2.4 km (1.5 mile) downstream from where stream empties into Yampa River	1.5
MC100E	Surface soil from 91 m (100 yd) E from E edge of tailings pile (TP)	98
MC200E	Surface soil from 182 m (200 yd) E from E edge of TP	26
MC375E	Surface soil from 343 m (375 yd) E from E edge of TP	16
MC200N	Surface soil from 182 m (200 yd) N from N corner of TP	38
MC350N	Surface soil from 320 m (350 yd) N from corner of TP in an old mill area yard where solution spill had occurred	260
MC500N	Surface soil 457 m (500 yd) N from corner of TP	67
MC600N	Surface soil 548 m (600 yd) N traverse from corner of TP	12
MC1500N	Surface soil 1371 m (1500 yd) N from corner of TP	2.3
MCRT1	Surface sample at center of overburden pile	27

Table 2 (Continued)

Sample designation	Sample location and description	Concentration of ^{226}Ra (pCi/g)
MCDW1	Surface sediment N of Hwy 40 where Johnson Wash goes under the highway	4.8
MCDW2	15 cm below surface at same point as MCDW1	3.6
MCDW3	Surface sediment 402 m (440 yd) due S of TP and E of overburden pile	6.9
MCDW4	15 cm below surface at same point as MCDW3	14
MCDW5	Surface sediment 228 m (250 yd) E of Sample 3 and 4	3.3
MCDW6	15 cm below surface at same point as MCDW5	4.5
MCDW7	Surface sediment from ~620 m (675 yd) east of overburden pile in Johnson Wash where 3 forks join	3.7
MCDW8	15 cm below surface at same point as MCDW7	4.2
MCDW9	Surface sediment from ~0.4 km (0.25 mile) S of sample MCDW7 and MCDW8	1.5
MCDW10	15 cm below surface at same point as MCDW9	2.3
MCDW11	Surface sediment from wash area S end of TP ~70 m (75 yd) from fence	73
MCDW12	15 cm below surface at same point as MCDW11	180
MCDW13	Surface sediment from Johnson Wash near SE corner of TP	22
MCDW14	15 cm below surface at same point as MCDW13	15
MCDW15	Surface sediment from Johnson Wash 130 m (140 yd) from fence	21
MCDW16	15 cm below surface at same point as MCDW15	7.3

4.4 Radiochemical Analyses of Water Samples

Water samples were obtained at six locations shown in Fig. 4 which are described in Table 3. These samples were analyzed using the technique described in Appendix III. The results are displayed in Table 3. Two of the samples, MCW1 and MCW3, exceed the concentration guide for drinking water⁹ (5 pCi/liter for $^{226}\text{Ra} + ^{228}\text{Ra}$) but it seems unlikely that water from either of the sources of these samples would be used for human consumption.

4.5 Distribution of ^{226}Ra in Subsurface Soil and Tailings

Holes were drilled at the locations shown in Fig. 5. Measurements of gamma exposure rate in these holes as a function of depth were made by FB&DU and ORNL personnel using the apparatus described in Appendix II. Since the subsurface gamma rays are primarily due to ^{226}Ra and several of its daughters, it is possible to calibrate the instrument and, thus, to convert the gamma exposure rate measurements to concentration of ^{226}Ra by comparing these measurements with concentrations of ^{226}Ra measured in soil collected at depths corresponding to the gamma measurements. The conversion was accomplished and the data were plotted (+) by use of a 9815A Hewlett-Packard desk calculator and the 9871A Hewlett-Packard printer. The printer supplies dots between + marks. The available analytical data for samples taken from several holes (excluding hole composite samples) were plotted (o) using the same equipment. The calculated distribution of ^{226}Ra in subsurface soil and tailings is displayed in Figs. 6-8, inclusive. Analytical data are in fair agreement with the calculated concentrations for holes 1 and 2 but not for hole 5. As has been observed in similar data obtained at other sites, the calculated concentrations at points below the interface are not reliable, probably because of gamma "shine" from adjacent sections of the holes, contaminated material dropping to the bottom of the hole, or the smearing action of the auger bit.

ORNL Photo 2162-79

Fig. 4. Locations and identifications of environmental samples.
Original photo by EG&G, Inc.

Table 3. Radiochemical analysis of water samples

Sample designation	Sample location	Nuclide concentration (pCi/liter)		
		²²⁶ Ra	²¹⁰ Pb	²³⁰ Th
MCW1	A 43-m (52-yd) deep well onsite SW of tailings pile (TP)	10	20	11
MCW2	Johnson Wash ~0.8 km (0.5 mile) below TP	0.02	a	80
MCW3	Johnson Wash at foot of TP	13	73	200
MCW4	From SE bank of stream that parallels Hwy 40 0.4 km (0.25 mile) to the east	0.2	a	0.2
MCW5	From same stream 2.4 km (1.5 mile) downstream at point where Johnson Wash empties into it	0.2	a	0.3
MCW6	~2.4 km (1.5 mile) farther downstream from MCW5 ~270 m (300 yd) from where stream empties into Yampa River	0.2	a	2.6

^aBelow detection limit.

ORNL Photo 2163-79

Fig. 5. Locations of holes drilled at the Maybell site. Original photo by EG&G, Inc.

Fig. 6. Calculated concentration of ^{226}Ra (pCi/g) in holes 1, 2, 3, and 4 (values noted by circles in holes 1 and 2 represent data from the analysis of individual soil samples).

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Fig. 7. Calculated concentration of ^{226}Ra (pCi/g) in holes 5, 7, and 9 (values noted by circles in hole 5 represent data from the analysis of individual soil samples).

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Fig. 8. Calculated concentration of ^{226}Ra (pCi/g) in hole 10.

The maximum calculated ^{226}Ra concentration in several holes is 600 to 800 pCi/g.

5. SUMMARY

The tailings pile at Maybell covers an area of approximately 30 hectares and the 2.4 million metric tons of tailings contains an estimated average ^{226}Ra concentration of 270 pCi/g. Above-ground gamma measurements defined the extent of spread of contamination toward the east and northwest. Radionuclide analyses of surface and near-surface soil and sediment samples also indicate the spread of tailings particles, especially in the dry washes that drain into Johnson Wash on the east side of the tailings pile. The ^{226}Ra concentration in sediment from a water sample at the point where the Johnson Wash reaches Lay Creek indicates that tailings particles have probably reached this point but there is no evidence that contamination has spread as far as the Yampa River.

Water from a 48-m deep well and stagnant water from Johnson Wash exceeded the concentration guide value for ^{226}Ra in drinking water. Calculated ^{226}Ra concentrations in holes drilled in the tailings area all showed maximum concentrations above 100 pCi/g and, in several holes, maximum values in the 600 to 800 pCi/g range were reached. Analytical data for soil samples from three holes are available to check the calculated ^{226}Ra concentrations, and fair agreement was noted for two of the holes.

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APPENDIX I

PHASE I

REPORT ON CONDITIONS OF URANIUM MILLSITE AND TAILINGS
AT MAYBELL, COLORADO

Site visited on May 9, 1974 by:

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to USAEC), Grand Junction, Colorado,
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This Phase I site investigation was conducted under a cooperative agreement among the Atomic Energy Commission, the Environmental Protection Agency and the State of Colorado. The report, prepared by Lucius Pitkin, Inc. under AEC Contract (AT(05-1)912, is reproduced directly from the best available copy with color photographs attached to the original report changed to black and white.

REPORT ON CONDITIONS OF URANIUM MILLSITE AND TAILINGS
NEAR MAYBELL, COLORADO

Introduction

Pertinent information has been accumulated from available records of the AEC, EPA, the States and companies involved. An on-site visit was made to note current conditions, including the millsite and the tailings disposal area, proximity to populated and industrialized areas, present ownership, and whether a need for corrective action exists. It is intended that this report will serve as a basis for determining the necessity of a detailed engineering assessment (Phase II).

This report on the site near Maybell, Colorado, was prepared jointly by the AEC, the EPA, and the State of Colorado's Department of Health, Division of Occupational and Radiological Health (CDH).

Summary and Conclusions

Union Carbide Corporation operated a uranium mill near Maybell, Colorado, for seven years. During that time 2.6 million tons of ore were processed and a similar quantity of tailings was produced. The tailings were originally impounded in a 51 acre tract, later the pile was leveled off and now covers an area of approximately 70 acres. After the mill shut down in November 1964 Union Carbide dismantled it and in 1971 started stabilizing the tailings in accordance with Colorado regulations. Additionally, Union Carbide fenced and posted the tailings area as required by the State. Union Carbide still controls all of the original holdings.

As a result of the site visit and review of available information, it is concluded that the following be considered in a Phase II study of the Maybell site:

- I. Examination of the millsite and its vicinity to determine extent of radioactive contamination and arrive at recommendations for decontaminations including utilization of nearby open pits for disposal of radioactive materials.
- II. Evaluate surface water drainage system and arrive at recommendations to prevent erosion of tailings.
- III. Improve stabilization of east slope of tailings pile to reduce impact of wind erosion.

Location

The Union Carbide Corporation, Maybell millsite is located 5.5 miles northeast of Maybell, Colorado, and approximately 4 miles north of Yampa River, Moffat County, Colorado, in Section 19, Township 7 North, Range 94 West, Sixth Principal Meridian and at 40°33' North latitude and 107°59'30" West longitude.

The millsite is located in the rolling hills adjacent to the Yampa River valley. Elevations range from 6,200 to 6,600 feet above sea level. (Photographs 1 and 2).

Ownership

The mining claims and millsite were located by Trace Elements Corporation in 1955 and 1956. This company subsequently became a subsidiary of Union Carbide Corporation. Union Carbide remains the owner of the property. The total area remains the same as during the operational period and is shown in Figure 1.

History of Operations

The mill was placed in operation in October 1957 with a capacity of 300 tons per day. The operation was shut down in November 1964. Records indicate 2.6 million tons of ore were processed with a grade of 0.098 percent U_3O_8 and all of the yellow cake from this operation was sold to the U.S. Atomic Energy Commission; all of the ore was produced from nearby open pit mining operations and the greater amount of ore was hauled by the equipment used in stripping.

Process Description

This plant had an upgrader circuit which was used to treat low grade ore before leaching.

Ore containing less than 0.20 percent U_3O_8 was classified into separate sand and slime fractions in the upgrader circuit with the sands rejected to waste and the slimes acid leached. Higher grade ore was acid leached directly and this leached slurry then treated in a six stage counter-current classification and washing circuit. The minus 325-mesh size slurry separated in this circuit was combined with the leached slimes from the upgrader circuit and the combined product then adjusted in pH and emf before ion exchange.

The resin-in-pulp ion exchange consisted of six absorption stages and 10 elution stages. An ammonium nitrate solution was used to elute uranium from the loaded resin and the uranium was precipitated from the eluate with anhydrous ammonia. 1/

Present Millsite

The tailings are all in one pile on relatively flat land, bounded on the west by the waste pile formed while mining an open pit and on the south and east by sagebrush covered land (Photograph 3) that drains into a dry drainage channel (Photograph 4) known as Johnson Wash. This wash in turn drains into Lay Creek a tributary of the Yampa River. The pile rises on a gentle slope of approximately 60 feet in height.

The Maybell tailings pile is in a remote locality with no nearby habitations. All mill buildings have been dismantled and removed from the property.

At the time the mill shut down the tailings disposal area covered 51 acres. Following contouring and covering of the tailings area and settling pond the total area stabilized is approximately 70 acres.

Drainage of the large surface area of the stabilized pile flows into a ditch running north to south on the top of the pile through a cut in the original retaining dike and over the southeast slope. During heavy rains this ditch would provide drainage for the top of the entire pile, thus subjecting it to intense erosion potential. The consensus of the survey team is that the ditch should be riprapped or in some way stabilized to reduce the washout potential.

The east slope of the stabilized pile follows the basic outline of the original retention dike. This slope is subjected to wind action such that establishing vegetation will be difficult.

The 70 acres of tailings have been contoured and covered to a depth of six inches with approximately 163,000 cubic yards of soil material from the nearby area. A three phase vegetation program was undertaken. Phase one vegetation done in 1971 involved the north top surface of the pile which had been partially utilized for slime disposal. (Photograph 5). Phase two took in the central area of the top surface and was concluded in 1972. (Photograph 6). Phase three performed by Union Carbide covered the south and west areas of the top surface and the east slopes along the original retention dike. The southern part of the top of the pile had also been utilized for slime deposition due to its lower elevation. Settling ponds to the south, southeast of the tailings area were filled with tailings during the stabilization, covered and vegetated in phase three. (Photograph 7).

The open pit area, millsite, settling ponds, and the tailings pile are fenced with locked gates and posted in compliance with regulations of the State of Colorado.

The site is under surveillance by Union Carbide Corporation's caretaker who resides in Maybell, and there is no evidence that tailings were removed from the Maybell pile.

W 95 W 67° PM of Colorado

W 94 W 67° PM of Colorado

TO MAYBELL
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Figure 1 Maybell Millsite

Environmental Considerations

The AEC mobile gamma scanner unit operated for EPA in cooperation with the Colorado Department of Health surveyed the towns of Maybell and Craig, Colorado, to determine the possible usage of tailings from the Maybell pile. The results of this study indicate no use in Maybell. 2/ The survey of the town of Craig, Colorado, in July 1971 located two anomalies later determined to be the result of the building material used and not the use of the tailings. No other environmental radiation surveys are known to have been done in the Maybell area.

One surveillance station was established on the Yampa River downstream from Maybell to measure Ra-226 (dissolved). The Ra-226 concentration for the period October 1961 - June 1972 was found to average 0.08 pCi per liter which is far below the maximum permissible concentration in drinking water of 3 pCi per liter for the general population. 3/

Based on 2.6 million tons of ore fed to the Maybell mill with an average grade of 0.098 percent U_3O_8 and assuming secular equilibrium the theoretical concentration of Ra-226 in the tailings from mill feed is about 270 pCi per gram of tailings. The total Ra-226 inventory in the tailings pile is estimated at 640 curies.

The mill recovery rate was 79.7 percent thus the tails should assay in the neighborhood of 0.02 percent U_3O_8 .

The present population of Maybell is 50 people but during the summer this increases to 75-100. Maybell at the present time is planning a sewage system for an ultimate population of 300 by 1984.

There is no planned industrial development for Maybell; however, exploration for oil and uranium in the vicinity will continue as drilling for oil was progressing at two locations within a mile and one-half of the millsite at the time of the site visit. The area holds potential for future uranium mining and milling activities should the demand for uranium increase sufficiently, as there are known ore reserves in this locality.

Meteorology

The average annual precipitation is about 11 inches per year with a snow fall of about 65 inches per year. The prevailing winds are from the west and southwest.

Hydrology

The uranium mill tailings are located approximately 5.5 miles northeast of Maybell, Colorado, and adjacent to Johnson Wash which is tributary to Lay Creek. The latter is a tributary of the Yampa River.

In general, ground water in the vicinity of the tailings area is at a depth of 70 or 90 feet below the land surface and well below the base of the tailings. In the Maybell area, the water table is quite shallow along the flood plain of the Yampa River which is floored in alluvium deposited within a channel incised in the Brown's Park formation. Considering the distance between Maybell and the tailings pile and other hydrogeologic factors, it is essentially impossible for the tailings pile to significantly increase the radionuclides content of the potable water at Maybell, which is obtained from shallow wells completed in the Yampa and Brown's Park formations.

Site Visit

The Maybell site was visited on May 9, 1974, by the following personnel (team) in the company of Robert G. Beverly, Director, Environmental Control, Mining and Metals Division, Union Carbide Corporation, James Massey, Plant Superintendent, Uravan Operations, Mining and Metals Division, Union Carbide Corporation, and Gordon Bitler, Caretaker Maybell site, Union Carbide Corporation.

Stanley A. Mayer, Lucius Pitkin, Inc., (Contractor to USAEC),
Grand Junction, Colorado,
Jon Yeagley, Environmental Protection Agency, Region VIII,
Denver, Colorado,
Don Lambdin, Environmental Protection Agency, Las Vegas,
Nevada,
Bert Crist, Colorado Department of Health, Denver, Colorado.

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2. U. S. Environmental Protection Agency, State and Community Summary Reports for Radiation Surveys (unpublished reports). (Craig and Maybell reports furnished Colorado Department of Health in March 1973), Office of Radiation Programs, Las Vegas, Nevada.
3. Radium-226, Uranium, and Other Radiological Data Collected From Quality Surveillance Stations Located in the Colorado River Basin of Colorado, Utah, New Mexico, and Arizona - January 1961 through June 1972.

1. West of the - 1961-1962

2. Union Carbide Corporation mill at Maybell.

3. Foreground sagebrush; right, slope of waste pile from open pit; center left, first phase of planted vegetation; top center, waste pile from open pit.

4. Start of construction of drainage ditch to take drainage from mine waste piles; right foreground, waste pile from open pit; center, showing drainage caused by excessive rainfall and drainage from mine waste pile.

5. First phase growth, yellow sweetclover, crested wheat grass, western wheat grass.

6. Second phase growth of vegetation on tailings pile.

7. Third phase growth of vegetation on tailings pile.

Soil Sampling and Measurement of Radionuclide Concentration as a Function of Depth in Soil

A monitoring and sampling procedure was established for this project in conjunction with FB&DU to measure the radionuclide concentration in soil as a function of depth. At each site, a set of 15-cm (6-in.) diameter holes was drilled through the tailings and into the subsoil. A polyvinyl chloride (PVC) pipe (7.6 cm o.d.), sealed on one end, was lowered into each hole, and measurements were made of gamma-ray intensities as a function of depth. A 15-cm-long Geiger-Mueller tube shielded with a lead cover containing collimating slits was used for this purpose by lowering it inside the PVC pipe for measurements. Signals from this detector were counted using a portable scaler.¹

After gamma-ray vs depth profiles were determined, the position of the interface between tailings and subsoil was estimated. Once completed, the drilling rig was moved approximately 1.2 m (4 ft), and another hole was drilled to the interface level. Samples of soil core were then collected as a function of depth using a split-spore sampler (each core section was 0.6 m long).

Most of the penetrating gamma radiation monitored is attributable to ^{226}Ra and its daughters. Therefore, a calibration factor for ^{226}Ra concentration was determined for the collimated gamma-ray probe by comparing the response of this unit (counts per unit time) with a measured value for the radium concentration (picocuries per gram) in several soil samples determined by a gamma-ray spectrometry technique. A least-squares fit of FB&DU data (first probe) from this comparison yields the equation

$$R = 0.528(C - 16)$$

For this case, R is the ^{226}Ra activity in picocuries per gram and C is the observed response of the collimated gamma-ray detector in counts per minute; there were 16 background counts per minute for the gamma-ray detector.

The above expression was useful in estimating the overall distribution of radioactivity in the tailings as well as the total quantity of radium in the tailings area. Surface soil samples were obtained normally by removal of an approximately 3-cm-deep layer of soil from an area of about 25 x 25 cm. The same procedure was used to obtain samples 15 cm (6 in.) below the surface except that the top 15-cm layer of soil was discarded and the sample was removed from the next 3-cm layer.

Each sample was dried for 24 hr at 110°C in order to remove moisture. The samples were then pulverized in a high speed rotary crusher having plates adjusted to provide particles no larger than 500 μ m. The soil was dispensed into 25-ml polyethylene vials of the type used for liquid scintillation counting and sealed tightly. A soil sample normally consists of 12 of these vials. The net weight of the group of vials was measured to the nearest tenth of a gram.

The sealed sample vials were stored for a period sufficient to allow attainment of equilibrium between ^{226}Ra and its short-lived daughters. Radon-222, which has a radioactive half-life of 3.8 days, will reach the same activity as its long-lived parent, ^{226}Ra , in about 30 days. The short-lived progeny of ^{222}Rn will have reached equilibrium within the same time. Determination of the activity of any of the daughters in the sample will reflect ^{226}Ra activity. After equilibration of radon daughters, the 12 sample vials (or smaller number) were inserted into a sample carousel or holder (Fig. II-1) that was placed on a Ge(Li) detector for counting as described in the section on gamma-ray spectrometry below.

Field Laboratory Facilities and Equipment

A 20-ft mobile laboratory van was used as a field office and for transporting instruments. This van contained an alpha spectrometry counting system for air samples along with air sampling equipment; a Johnston Laboratory radon monitor complete with Lucas-type flasks and an evacuation manifold; gamma-ray detectors; miscellaneous electronic testing equipment; and standard calibration sources. A trailer-mounted, gasoline-powered 12 kW motor generator, pulled by the van, was used to

ORNL-Photo 2i71-75

Fig. II-1. Horizontal mounted Ge(Li) detector system used for counting soil samples (carousel-type sample holder is shown in its counting position).

supply electrical power in remote locations. A voltage stabilizer was used to provide regulated power for instruments.

A second field laboratory used in the project was an 8 x 35 ft air-conditioned semitrailer with running water, tools, and miscellaneous supplies. It served as an instrument calibration facility, office, and workshop. This trailer required electrical power from an external source. During most of this project, the trailer was parked in Grand Junction and was used as a temporary field office.

Gamma-Ray Spectrometry Systems

A Harshaw integral 3 x 3 in. NaI (Tl) crystal, a high sensitivity detector, was used to scan all samples for a preliminary estimate of ^{226}Ra activity. This detector was used in a "pickle barrel" type shield, lined with copper and cadmium to shield x-rays. Signals from the crystal were sorted by a computer-based (PDP-11) pulse-height analyzer. The computer was programmed to control all functions of the analyzer and counter, to analyze the data, and to print out a statistically weighted average of the ^{226}Ra activity per unit mass. One advantage of this counting arrangement is that it permits quick sorting; samples can be scanned at the rate of about six per hour (minimum counting period is 5 min).^{*} An energy calibration of the NaI crystal and analyzer was obtained by standardizing with ^{57}Co , ^{137}Cs , and ^{60}Co . An efficiency calibration was obtained through daily counting of a uranium standard[†] (0.05% uranium mixed with dunite, particle size = 500 μm). Radium-226 is in equilibrium with the uranium, and this isotope and its daughters provide a source of gamma-ray lines for calibration.

^{*}The principal reason for using this scanning system was to estimate how much time would be required to count the samples with one of three high resolutions Ge(Li) gamma-ray spectrometers.

[†]Standard uranium sample obtained from the former Atomic Energy Commission New Brunswick Laboratory.

Final data on the concentration of radionuclides in soil samples were determined by counting all samples with one of three high resolution Ge(Li) spectrometers. These high resolution counting systems consist of one horizontally mounted 50-cm³ Ge(Li) crystal positioned on a platform for movement into and out of a lead shield (Fig. II-1), and two vertically mounted detectors (Fig. II-2). The detector systems were used to obtain complete photon spectra of the soil samples. Signals from the horizontal Ge(Li) crystal were routed to a 4096-channel pulse height analyzer and signals from the other two Ge(Li) crystals were routed to two 2688 channel regions of a computer based pulse height analysis system. Samples were counted for periods long enough to evaluate the ²²⁶Ra concentration to a statistical accuracy of $\pm 5\%$ or better. Spectra from the horizontally mounted Ge(Li) detector were recorded on magnetic tape and stored for later analysis using the ORNL IBM computer system.*

The computers were programmed to sort out peaks from ²³²Th daughters including the 909 and 967 keV peaks from ²²⁸Ac, the 239 keV from ²¹²Pb, and the 2614 and 583 keV peaks from ²⁰⁸Tl. These data permitted measurements of the ²³²Th concentration and data are reported for many of the samples.

Energy calibration of the Ge(Li) detectors was controlled through the use of isotopic sources of ⁵⁷Co, ²²Na, ¹³⁷Cs, ⁶⁰Co, ⁸⁸Y, and ⁴⁰K. A calibration check was completed each day prior to beginning sample counting. In order to maintain linearity of the ADC's, a spectrum stabilizer was utilized. This instrument can be adjusted so that two individual photon energies are detected and maintained in two channels at separate ends of the scale. These two calibration points helped maintain an energy span of 1 keV per channel. Efficiency calibration was obtained through the use of the same uranium ore standard samples as for the NaI crystal. An analysis of the counting data was accomplished

*Spectra from the two vertically mounted Ge(Li) detectors were stored on magnetic tape for record purposes, but were analyzed immediately using a Tencomp Model TP-5/11 computer-based analyzer.

Fig. 11-2. Computer based multichannel analyzer and one of three Ge(Li) counting systems.

through a linear least-squares fitting routine. Net adjusted areas under photo peaks of interest were compared with an extensive radio-nuclide library.² Data from the computer were presented for each radio-nuclide as a weighted mean with standard deviation.

External Gamma-Ray Detector

A gamma radiation survey was made on and around the mill site and tailings pile. The instrument used for these measurements was a "Phil" gamma-ray dosimeter.³ The basic unit was a 15-cm- (6-in.) long 30-mg/cm² glass-walled organic-filled Geiger-Mueller (G-M) tube with an energy compensation shield made of tin and lead. Pulses from this unit were counted with a battery-powered portable scaler. Typically, G-M counters are not used for dosimeters because of a peaked response at low photon energies. However, perforated layers of tin (1.0 mm), and lead (0.1 mm), were used as an energy compensation filter to flatten this peaked response at photon energies below about 200 keV. Sealed sources of ¹³⁷Cs and ²²⁶Ra were used for calibration. It was found that the response of this detector was: 1 mR/hr = 3400 counts/min.

For each gamma-ray-exposure rate measurement, at least three 1-min counts were recorded. The mean of these readings (less instrument background) was used to determine the exposure rate to external gamma rays.

Radon Daughter Sampler*

Radon daughter concentrations were measured with a sampling and counting instrument which has been in use at ORNL for several years,⁴ and it was also used to make some comparative measurements in the remedial action program in Grand Junction.⁵ The filter counter for this sampling device, shown in Fig. II-3, utilized a modified gas flow alpha

*This section and the following section contain descriptions of devices and methodologies typically used in the radiological surveys of milling facilities. They are included in each report in this series. However, in some instances, the measurements were not possible.

Fig. II-3. System used for measurement of radon daughter concentrations.

counter for housing a 450-mm² silicon diode. Normally, this type detector is operated in a vacuum chamber. However, in this case, it was found that by flowing helium at atmospheric pressure through the assembly, absorption of alpha particles is small relative to absorption in air. Alpha particle pulses were recorded with a 100-channel analyzer. A small ²²⁸Th alpha source standard was used for standardizing the energy scale. Air that was monitored for radon daughters was sampled at a rate of 12 to 14 liters/min. An absolute calibration of the airflow was provided through a comparison of the sampler's mass flow meter and a wet test meter. Samples were normally collected for 10 min, and the first count of the filter was started at 2 min after removal of the sample and continued for 10 min. For this case, a determination was made of the number of counts due to the decay of ²¹⁸Po (RaA) and ²¹⁴Po (RaC'). A second count was started 15 min after removal of the sample and continued for 15 min. In this case, counts were recorded from the decay of ²¹⁴Po. Data from the counter were stored in a pulse height analyzer and reduced by computer. The code for this analysis is explained in detail elsewhere.⁶ Results of the analysis of data using this code were presented as concentrations of RaA, RaB, and RaC'. In addition, a value for the working level concentration was also provided along with an estimate of the error associated with each reported value.

Radon Monitor

The instrument used by ORNL to measure radon concentrations in air consisted of 95-ml Lucas chambers and a readout unit.* Each chamber was evacuated to approximately 1 mm Hg and then opened to atmospheric pressure in the area where a radon measurement was required. No filtration was used for sampled air. The short-lived daughters of radon drawn into the chamber were allowed to decay for 3 to 4 hr prior to counting the flask. Comparison of the results from this instrument and the radon

*LLRC-2 Low Level Radon Counting System manufactured by Johnston Laboratories, Inc., Baltimore, Md.

progeny monitor provided an estimate of the degree of equilibrium between radon and its daughters in the selected locations where air samples were taken.

APPENDIX II REFERENCES

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APPENDIX III

Water Sampling and Analysis

Water samples are obtained at appropriate points on and around the mill site, labeled and stored for later analysis. Each sample is centrifuged and filtered through a 0.45- μ m filter to remove suspended solids. The samples are then analyzed by radiochemical techniques as described in this appendix.

Procedure for the Sequential Determination of ^{226}Ra , ^{230}Th ,
and ^{210}Pb in Water from Uranium Mill Tailings Sites

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1.0 Radium-226

- 1.1 Filter the ~1.0 liter water sample using a vacuum flask and #42 Whatman filter paper to remove suspended particles.
- 1.2 Reduce the volume of the water sample, to which 10 ml of concentrated HNO_3 has been added, to less than 250 ml by evaporation.
- 1.3 Transfer the solution to a 250-ml, long-neck, tapered-joint, flat-bottom Pyrex boiling flask. Insert a Teflon-coated magnetic stirring bar. Add 37 ml of concentrated HNO_3 to make the final concentration 3%. Insert the modified, female, tapered joint with gas diffuser and side arm with stopcock. Seal off the gas inlet and close the stopcock to assure containment of ^{222}Rn in the flask. Store for at least 30 days to await attainment of ^{226}Ra - ^{222}Rn equilibrium.
- 1.4 Next, connect the 250-ml de-emanation flask to a helium source and the radon trapping system. Attach an evacuated Lucas chamber. Flush the system with helium gas while bypassing the flask. Stop the gas flow. Immerse the unfired Vycor radon concentrator in a liquid nitrogen bath. Be sure the upstream exit for helium gas is open. Start the magnetic stirrer. Open the flask side arm stopcock to the system and start helium gas flowing through the liquid at a rate not to exceed 2.8 liters/hr. The radon-helium stream is dried and stripped of organic condensable components by KOH and ascarite traps. Radon is condensed on the Vycor at liquid nitrogen temperature and thus separated from the helium gas carrier.

- 1.5 Stop the de-emanation process after 30 min. Having shut off the gas flow, close the helium exit. Isolate the radon trap and the evacuated Lucas chamber from the remainder of the system via stopcocks.
- 1.6 Open the Lucas chamber stopcock and remove the liquid nitrogen from the radon trap to allow the gaseous radon to diffuse into the chamber. To hasten the diffusion, the trap may be gently flamed.
- 1.7 Bypassing the flask, use a controlled stream of helium to flush residual radon into the Lucas chamber until near atmospheric pressure has been reached. Stop the gas flow and close the stopcock on the Lucas chamber.
- 1.8 After a delay of 3.0 to 3.5 hr to permit the ^{222}Rn to reach equilibrium with its daughters, place the Lucas chamber over a photomultiplier tube and count the gross alpha for 30 min.
- 1.9 Subtract the Lucas chamber background, counted under the same conditions, from the gross count. Divide the net count by three to obtain the ^{222}Rn count at that time. Correct the count for time elapsed since de-emanation was terminated and the efficiency of the Lucas chamber for converting alpha discharges to scintillations (~85%). Report the ^{226}Ra in equilibrium with ^{222}Rn as picocuries per liter.

2.0 Thorium-230

- 2.1 Transfer one-half of the water sample remaining from the radon de-emanation process (3 M HNO_3) to a Pyrex beaker for volume reduction on a magnetic stirrer hot plate.
- 2.2 Add 0.7 g $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, 2.0 ml (20 mg) Pb carrier, 1.0 ml (20.9 mg) Bi carrier and 5,000 to 10,000 cpm of ^{234}Th tracer to the water sample before reducing the volume to approximately 20 ml.
- 2.3 Should the sample solution contain undissolved salts, separate liquid and solids by use of centrifuge. Dissolve the

solids by heating with a minimum volume of distilled water or dilute HNO_3 . Combine the dissolved solid with the original supernate. Could silicic acid form in the solution during volume reduction, as evidenced by its deposition on the beaker walls, cool the solution to room temperature and centrifuge. Add an equal volume of concentrated HNO_3 to the supernate. Wash the solids with a small volume (5.0 ml) of 8 M HNO_3 and centrifuge. Combine the wash with the adjusted supernate. Discard the solids. Keep the solution cool in an ice bath during precipitation of hydroxides with an excess of ammonium hydroxide to minimize the formation of silicic acid from dissolved silicates. Let stand 5 to 10 min. Centrifuge, pour off the supernatant liquid, and wash the precipitate with dilute ammonium hydroxide. Discard the supernatant and wash liquids. Dissolve the solids in 10-20 ml of 8 M HNO_3 . Should the solution contain suspended silicic acid, centrifuge, wash the solids with 5 ml of 8 M HNO_3 and combine the supernatant liquids. Discard the solids.

- 2.4 Transfer the 8 M HNO_3 solution to a conditioned Dowex 4 x 1 anion exchange column 5 mm i.d. x 10 cm long (~2.0 ml vol.). The column is conditioned by passing through it at least 5 column volumes (10 ml) of 8 M HNO_3 . The anion-complexed thorium adsorbs on the resin column to the exclusion of the cations. Wash the column with 10 ml of 8 M HNO_3 to remove residual bismuth. Combine the effluent and wash solutions, and save them for lead and bismuth recovery.
- 2.5 Strip the thorium from the column with 5.0 ml of distilled water followed by 10 ml of 6 M HCl .
- 2.6 Convert the chloride to the nitrate by adding an excess of HNO_3 and reducing the solution to near dryness on a hot plate. Dissolve the solids in 5.0 ml of 0.1 M HNO_3 .
- 2.7 Transfer the 0.1 M HNO_3 solution to a conditioned Dowex 50 x 1 mm cation exchange 2.5 mm i.d. x 7 cm long (~0.4 ml vol.). The column is conditioned by passing 5.0 ml 8 M HNO_3 through

- it and then washing it free of excess acid with distilled water as indicated by litmus paper.
- 2.8 Wash the column with 5.0 ml of 2 M HCl to remove traces of bismuth and other weakly bound cations.
 - 2.9 Strip the thorium with 5.0 ml of 8 M HNO₃ and reduce the volume of the solution to a few drops by evaporation.
 - 2.10 Transfer the solution with a suitable pipette onto a 2-in. stainless-steel disc supported on a hot plate by a steel washer 0.75 in. i.d. x 1.5 in. o.d. Dry slowly to minimize the deposit area at the center of the disc. Fire the disc to red heat with a gas torch to remove carbonaceous materials.
 - 2.11 Determine the thorium yield by counting the ²³⁴Th beta with an end window counter and compare it with a mounting of like count of the ²³⁴Th tracer used in the analysis.
 - 2.12 Determine the ²³⁰Th alpha disintegrations per minute (dpm) by pulse-height analysis using a diode pickup in a helium atmosphere. Compare the counts of ²³⁰Th alpha in the sample with those in a ²³⁰Th standard mounting whose dpm is known.
 - 2.13 To correct for the contribution of ²³⁰Th which may be in the ²³⁴Th tracer, pulse analyze the ²³⁴Th mounting. Subtract the contribution from the tracer after correcting for yield to obtain the net ²³⁰Th content of the water sample.
 - 2.15 Calculations

$$^{230}\text{Th}(\text{pCi/liter}) = \frac{AB}{CDEF},$$

where

- A = Water sample net alpha (cpm)
- B = ²³⁰Th standard (dpm)
- C = ²³⁰Th standard (cpm)
- D = Fraction of ²³⁴Th tracer recovered
- E = Volume of sample (liter)
- F = 2.22 d/(m·pCi)

3.0 Lead-210

- 3.1 Evaporate the Dowex 4 x 1 effluent and wash from Step 2.4 to ~20 ml. Cool and slowly add ammonium hydroxide, while stirring in an ice bath, until hydroxide precipitation barely starts. Add 1 to 2 drops of concentrated HNO_3 to each 10 ml of solution to give an acidity of 0.2 to 0.4 M.
- 3.2 Slowly bubble H_2S through the chilled solution to precipitate metal sulfides. Let the mixture stand 10 to 15 min and centrifuge. Discard the supernate. Wash the sulfides with 5 to 10 ml of H_2S -saturated 0.2 M HNO_3 solution. Centrifuge and discard the wash.
- 3.3 Dissolve the sulfide precipitate in a minimum of concentrated HNO_3 by heating in a hot water bath. Dilute with 5 to 10 ml of distilled water and filter out the suspended sulfur on #42 Whatman filter paper. Wash out the centrifuge tube and filter with 5 to 10 ml of distilled water.
- 3.4 Transfer the solution to a centrifuge tube and precipitate the hydroxides with an excess of ammonium hydroxide. Digest 10 min in a hot water bath. Cool, centrifuge, and wash the precipitate with 5 to 10 ml of dilute NH_4OH . Discard the supernatant and wash liquids.
- 3.5 Dissolve the hydroxides in a minimum of concentrated HNO_3 and dilute to 10 ml. Add 0.5 ml of concentrated H_2SO_4 to precipitate PbSO_4 . Digest 15 min in a hot water bath, cool, centrifuge, and wash the PbSO_4 with distilled water. Save the supernatant and wash liquids for bismuth recovery.
- 3.6 Transfer the PbSO_4 slurry onto a tared #42 Whatman filter paper disc which is supported by the perforated fixed plate of a Hirsch funnel. Dry the PbSO_4 and paper with ethyl alcohol followed by ethyl ether.
- 3.7 Weigh the filter paper and PbSO_4 to determine the yield of ^{210}Pb . Store the $^{210}\text{PbSO}_4$ sample for 30 days to allow the ^{210}Pb to reach equilibrium with its ^{210}Bi daughter. The ^{210}Bi beta is counted in a low-level gas-proportional counter with a

1-mil-thick polystyrene cover to shield out any stray alpha emissions.

- 3.8 Add pellets of NaOH to the bismuth solution from Step 3.5 to precipitate bismuth hydroxide. Digest for 10 min in a hot water bath, cool, and centrifuge. Wash the precipitate with 10 ml of distilled water. Discard supernatant and wash liquids.
- 3.9 Dissolve the solids in a minimum of HNO_3 . Add 3-4 drops of concentrated HCl and dilute to ~40 ml with hot distilled water to precipitate BiOCl . Digest for ~45 min in a hot water bath or until the precipitate has settled.
- 3.10 Pour the hot supernatant liquid through a tared #42 Whatman filter paper supported by a perforated, fixed-plate, Hirsch funnel. Slurry the BiOCl onto the filter paper disc with small portions of hot distilled water. By means of a stirring rod, guide the deposit to the center of the disc. Dry with ethyl alcohol and ethyl ether.
- 3.11 Weigh the BiOCl and filter paper in order to determine yield.
- 3.12 Count the 5.01 day ^{210}Bi beta, which is in equilibrium with ^{210}Pb , in a low-level, gas-proportional counter. The counting efficiency of the counter is determined by counting several similar mountings having known ^{210}Bi disintegration rates, with varying weights of BiOCl from which a calibration curve is constructed.
- 3.13 Refer to the calibration curve and convert cpm to dpm by means of an efficiency factor for the weight of sample in question.
- 3.14 Calculation

$$^{210}\text{Pb} \rightarrow ^{210}\text{Bi}(\text{pCi/liter}) = \frac{AB}{\text{COEF}},$$

where

A = Beta count minus background (cpm)

B = Correction for decay from Pb separation time
to counting time

C = Counter efficiency
D = Fraction of Bi recovered
E = Volume of sample (liter)
F = 2.22 d/(m·pCi)

4.0 Reagents

- 4.1 Aluminum nitrate.
- 4.2 Lead carrier, 10 mg/ml. Dissolved 8.0 g $\text{Pb}(\text{NO}_3)_2$ in dilute HNO_3 and dilute to 500 ml with water.
- 4.3 Bismuth carrier, 20.9 mg/ml. Dissolve 5.225 g bismuth metal in concentrated HNO_3 and dilute to 250 ml with water.
- 4.4 Thorium tracer, ^{234}Th . Pretreat a 30% Adogen 364-Xylene solution by extracting it with an equal volume portion of 2 M HNO_3 for 2 min. Dissolve 5.0 g of recently depleted ^{238}U (as U_3O_8) in 2 M HNO_3 . Extract the thorium and uranium with an equal volume of pretreated 30% Adogen 364-Xylene in a separator flask by hand shaking at least 2 min. Separate phases and strip thorium from the solvent with 10 ml of 10 M HCl . Convert the chloride solution to 2 M HNO_3 solution for a repeat extraction with solvent to remove traces of uranium. The second 10 M HCl strip is again converted to the nitrate for counting the ^{234}Th beta on a stainless steel disc. The mounting should be examined in a pulse-height alpha analyzer for the presence of ^{230}Th . Should the ^{230}Th level be significant, then another source of depleted ^{238}U should be sought, or alternatively extract the ^{234}Th from a batch of ^{238}U from which the thorium had been extracted 1 to 2 months previously.
- 4.5 Ammonium hydroxide, concentrated.
- 4.6 Nitric acid, concentrated.
- 4.7 Hydrochloric acid, concentrated.
- 4.8 Sodium hydroxide pellets.
- 4.9 Sulfuric acid, concentrated.

4.10 Hydrogen sulfide gas.

4.11 Dowex 4 x 1 and Dowex 50 x 1 exchange resins.

5.0 Apparatus

5.1 Radon de-emanation train with radon concentrator* and Lucas chamber.

5.2 Radon photomultiplier counter.

5.3 Modified[†] 250-ml, flat-bottom, boiling flasks.

5.4 Other counting equipment--G-M beta counter; low-level, gas-proportional beta counter; pulse-height spectral alpha analyzer.

5.5 Stainless-steel alpha counting discs.

5.6 Laboratory centrifuge.

5.7 Pyrex centrifuge tubes, 50 ml.

5.8 Beakers, assorted.

5.9 Ion exchange columns.

5.10 Dowex 4 x 1 and Dowex 50 x 1 exchange resins.

5.11 Hirsch fixed plate funnel.

*The radon concentrator consists of a 20-cm-long U-tube constructed from 6 mm o.d. Pyrex glass tubing. Ten centimeters of the U-section is filled with 20 to 40 in. unfired Vycor which has a large surface to volume ratio. When the tube is immersed in liquid nitrogen and radon-laden helium gas passes through the tube, the condensable radon adheres to the Vycor surface. The stripped helium gas exits the system. Upon removal of the coolant the radon vapor diffuses through 10 to 15 cm of capillary tubing to the evacuated Lucas chamber. Flushing the U-tube and attached capillary tubing with 20 to 30 ml of helium transfers essentially 100% of the radon to the Lucas chamber. Since the efficiency of Lucas chambers for counting alphas may vary from 75 to 85%, it is necessary to calibrate each chamber with an equilibrated ²²⁶Ra standard solution.

[†]The radium-radon equilibrating flask consists of a flat-bottom 250-ml boiling flask with a female 24/40 tapered joint. A saber-type sintered glass gas diffuser is sealed into a male 24/40 taper joint section so that when it is inserted in the flask it will extend well into the equilibrating solution. A suitable inlet gas connection is provided on the opposite end of the diffuser tube. Onto the shoulder of the male 24/40 joint is sealed a short length of small bore (5 mm i.d.) glass tubing with a glass stopcock terminating with a connector suitable for hooking up with the radon trapping system.

ACKNOWLEDGEMENTS

The authors of this series of reports wish to express their deep appreciation to the following persons: to L. J. Deal and R. H. Kennedy, Department of Energy, Washington, D. C., for their encouragement and support during the field operations phase of this project; to Dr. Charles J. Barton of Science Applications, Inc. (SAI), Oak Ridge, for his diligent work in preparing, under subcontract, the drafts of this series, and to Wilma Minor, also of SAI for typing the manuscripts; to the many members of the Health and Safety Research Division who provided technical reviews of the individual reports; to Jenny Vinson, Health and Safety Research Division Technical Editor, special thanks is extended for her careful review of each manuscript, especially for helping ensure that a uniform format was followed; to Dr. Barry Berven for his assistance in organizing the final drafts. Appreciation is extended to John G. Themelis and Frank McGinley, Department of Energy, Grand Junction Operations Office, for their support and advice during the conduct of this project; to Charles Brunner, Bendix Field Engineering Company, Grand Junction, Colorado, for his assistance in arranging for the grinding of approximately 1600 soil samples which were collected during the project; also to Dr. Vern Rogers and his staff, Ford, Bacon and Davis Utah Inc., for assistance during the field operations phase of this project. Finally, the authors wish to acknowledge the efforts of Mr. Ev Haldane, Department of Energy, Grand Junction, who was associated with the uranium-mill tailings program from its earliest days. Ev passed away suddenly on June 30, 1979, and it is to his memory that this series of reports is dedicated.