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Radiological Survey of the Inactive Uranium-Mill Tailings at Lakeview, Oregon

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**RADIOLOGICAL SURVEY OF THE INACTIVE URANIUM-MILL
TAILINGS AT LAKEVIEW, OREGON**

F. F. Haywood, J. E. Burden, B. S. Ellis,
E. T. Loy, and W. H. Shinpaugh

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RADIOLOGICAL SURVEY OF THE INACTIVE URANIUM-MILL
TAILINGS AT LAKEVIEW, OREGON

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ABSTRACT

The results of the radiological survey of the inactive uranium-mill site at Lakeview, Oregon, presented in this report, show that the average gamma-ray exposure rate 1 m above the tailings pile and the evaporation pond area (now dry) is close to the average background level for the area (11 $\mu\text{R/hr}$). The ^{226}Ra concentration in most of the surface soil and sediment samples is also at or below the average background value for surface soil samples in the area (0.8 pCi/g). Calculated ^{226}Ra concentrations, based on gamma radiation measurements in shallow (1-m-deep) holes, are in agreement with the results of surface soil and sediment analyses and with gamma-ray exposure rate measurements. The tailings at this site have been stabilized by the addition of 46 to 60 cm (18 to 24 in.) of soil that supports vigorous growth of vegetation. This treatment, coupled with a low-level inventory of ^{226}Ra in the tailings (50 Ci), has resulted in limited spread of tailings by wind and water.

1. INTRODUCTION

This is one of a series of reports on results of radiological surveys of uranium-mill tailings at inactive mill sites in the western United States. A list of the reports in this series is found at the front of this report. The first four reports, as well as the one on the Grand Junction site, include attempts to assess potential health effects of radiation and radionuclides from the sites. The first report¹ 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. The present report on the inactive mill site near Lakeview, Oregon, presents the results of a radiological survey conducted in 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. (FB&DU), 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.² Results of a gamma radiation survey of these sites [by the Environmental Protection Agency (EPA)] have also been published.³ The previously unpublished Phase I engineering survey report on the visit to the Lakeview site by Barney et al. is included in Appendix I. Several publications⁴⁻⁹ 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 Lakeview, Oregon, and a history of the operations at this site are included in the Phase I engineering survey report (Appendix I) and only a brief summary of this information is presented here.

The Lakeview site, owned by Atlantic Richfield Company (ARCO), is located 3 km (1.9 miles) northwest of the city of Lakeview. An aerial photograph of the site and surrounding area is shown in Fig. 1. Two separate areas make up the tailings pile; one area covers approximately

ORNL-Photo 0535-79

Fig. 1. Aerial view of the Lakeview site and surrounding area.
Source: EG&G, Inc.

14 hectares (35 acres), whereas the second area covers 12 hectares (30 acres). The entire Lakeview site is described² as covering an area of 104 hectares (258 acres) (Appendix I). The evaporation ponds cover an area of about 26 hectares (64 acres).² Operation of the uranium mill lasted from 1958 to 1961. During this time, approximately 118,000 metric tons of ore containing an average U_3O_8 content of 0.15% were processed. The tailings pile is estimated to have a theoretical concentration of ^{226}Ra of 427 pCi/g and to contain a total of 50 Ci of this isotope (Appendix I).

Most of the mill buildings at this site were intact at the time of this survey. Atlantic Richfield is reported to have decontaminated the mill building and to have removed machinery and other salvageable items from the site. The tailings pile was covered with soil to a depth of approximately 46 to 60 cm (18 to 24 in.). This cover supports a vigorous growth of vegetation. The tailings pile is surrounded by a hog-wire-type fence, and the entire site has a barbed wire fence around it. Evidence of wind erosion of the tailings pile was reported by FB&DU.²

3. SAMPLING TECHNIQUES AND RADIOLOGICAL MEASUREMENTS

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

4. RESULTS OF MEASUREMENTS

Measurements were made at the Lakeview site to determine: (1) background external gamma radiation levels and background radionuclide concentrations in surface soil samples; (2) external gamma-ray exposure rates 1 m above the ground at the site; (3) radionuclide concentrations in surface or near-surface soil samples; (4) radionuclide concentrations in water samples; and (5) the subsurface distribution of ^{226}Ra . Because of the short term of the survey, no attempts were made to measure the

concentration of radon, radon daughters, or other airborne radionuclides. Results of the various types of measurements are discussed in separate sections 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 if they are required.

Locations are shown in Fig. 2 where background measurements were made of external gamma-ray exposure rates 1 m above the ground and where surface soil samples were obtained for analysis. 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-ray exposure rate 1 m above the ground from 8 to 19 $\mu\text{R/hr}$. The average value of 11 $\mu\text{R/hr}$ corresponds to an annual background dose equivalent of 96 millirems. The average ^{226}Ra concentration in surface soil samples is 0.8 pCi/g. There is not a good correlation between the direct gamma-ray exposure rate above the ground 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 in gamma radiation measurements resulting from the small amount of activity in the samples.

4.2 Direct Gamma-Ray Exposure Rates

Measurements were made of direct gamma-ray exposure rates 1 m above the ground using a glass-walled Geiger-Mueller (G-M) tube ("Phil") described in Appendix II. These measurements were made at 46-m (50-yd) intervals. The data show exposure rates over the tailings pile ranging from 9 to 53 $\mu\text{R/hr}$ with an average value of 16 $\mu\text{R/hr}$ (Fig. 3). The range for the evaporation ponds is 2 to 24 $\mu\text{R/hr}$ with an average of 10 $\mu\text{R/hr}$. The average exposure rate in the mill area is 35 $\mu\text{R/hr}$, with a maximum reading of 96 $\mu\text{R/hr}$.

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

Table 1. Locations of background external gamma measurements and background surface soil samples around Lakeview, Oregon

Sample point	Location	External γ exposure rate ^a (μ R/hr)	Nuclide concentration (pCi/g)		
			²²⁶ Ra	²³² Th	²³⁸ U
OE1	Oregon and Utah border at northeast side of Hwy 140	19	2.1	1.5	0.8
OE2	Northside of Hwy 140 ~1.6 km	10	0.2	0.5	0.2
OE3	0.8 km N of California border on W side of Goose Lake	13	^b	0.7	0.3
OE4	S side of Hwy 140 ~1.6 km W of Quartz Mountain	8.3	0.4	0.4	0.2
OE5	Intersection of Hwys 395 and 31	9.7	0.6	0.6	0.2
OE6	N side of Hwy 31 at west side of Paisley, Oregon	9.5	0.8	0.7	0.4
OE7	E side of Hwy 395 across hwy from Wagontire	10	0.8	0.7	0.3
OE8	8 km E of Burns, Oregon on S side of Hwy 20	12	1.0	0.9	0.4
OE9	S side of Hwy 20 W of city limits of Juntura, Oregon	8.2	0.6	0.5	0.2
CA1	W side of US 395 at junction of Hwy 395 and County Road 46	9	1.3	0.8	0.5
CA2	E side of Co. Rd. 48 S of Goose Lake	11	0.8	0.6	0.4
CA3	E side of county road on W side of Goose Lake at Crowder Flats turn off	11	0.2	0.3	0.1
	AVERAGE	11	0.8	0.7	0.3

^aOne meter above the ground.

^bNo data available for this nuclide.

The data in Fig. 3 show low exposure rates over the tailings pile and the evaporation ponds; there is no evidence of significant spread of contamination from either part of the site. The highest readings in the vicinity of the tailings pile were at the eastern edge of the pile (53 $\mu\text{R/hr}$) and a few meters north of the pile (37 $\mu\text{R/hr}$). The exposure rate in the former mill area is moderately low but is higher than that existing in the areas of the tailings pile or evaporation ponds.

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

Analysis of soil and sediment samples for ^{226}Ra supplements the measurements of above-ground gamma rays 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. Results are displayed in Table 2. Environmental sample locations are shown in Fig. 4, including the locations of water samples discussed below. Soil and sediment sample locations are also described in Table 2.

It is evident from the data in Table 2 that surface contamination with ^{226}Ra is low in the vicinity of the Lakeview tailings pile and the evaporation ponds, in agreement with the results of the gamma-ray exposure rate measurements discussed in the previous section. The dry-wash* samples show no evidence of significant movement of tailings particles by water erosion, and the surface soil samples indicate that wind erosion of the tailings pile has also not produced significant spread of contamination at this site. At each water sample location, a sample of sediment was collected from the floor of the water body. The samples were analyzed according to the techniques described in Appendix II. Results are displayed in Table 2.

*A dry-wash area may be described as an area of apparent surface water drainage away from a tailings pile. In these areas, samples were collected on the surface and at 15 cm (6 in.) below the surface at regular intervals along this drainage path.

ORNL-Photo 5154-79C

Fig. 3. External gamma exposure rates ($\mu\text{R/hr}$) 1 m above the ground at the Lakeview site. Original photo by EG&G, Inc.

Table 2. Concentration of ^{226}Ra and ^{232}Th in surface soil and sediment samples at the Lakeview site

Sample designation	Sample location and description	Nucleic concentration (pCi/g)	
		^{226}Ra	^{232}Th
ZDW1	Surface sediment from dry wash in a ditch running S at S end of tailings pile (TP) ~3 m (10 ft) S of TP fence	0.2	a
ZDW2	Sediment from same location as ZDW1 but 15 cm below surface	0.5	0.5
ZDW3	Surface sediment from dry wash in a ditch running south at S end of TP 91 m (100 yd) S of fence	0.5	0.5
ZDW4	Sediment from same location as ZDW3 but 15 cm below surface	0.5	0.5
ZDW5	Surface sediment from dry wash S of TP fence	1.1	0.9
ZDW6	Sediment from same location as ZDW5 but 15 cm below surface	0.6	0.5
ZDW7	Surface sediment from dry wash 136 m (150 yd) S of TP	1.0	0.7
ZDW8	Surface sediment from same location as ZDW7 but 15 cm below surface	0.5	0.5
ZDW9	Surface sediment from dry wash in a ditch northeast corner of Pond 9	0.9	0.4
ZDW10	Sediment from same location as ZDW9 but 15 cm below surface	0.5	0.5
ZDW11	Sediment from surface dry wash in a ditch at logging road from NE corner of TP	0.6	0.6
ZDW12	Sediment from the same location as ZDW11 but 15 cm below surface	0.6	0.6

Table 2. (continued)

Sample designation	Sample location and description	Nuclide concentration (pCi/g)	
		²²⁶ Ra	²³² Th
ZDW13	Surface sediment from dry wash in a ditch 90 m E of logging road from NE corner of TP	0.5	0.5
ZDW14	Sediment from same location as ZDW13 but 15 cm below surface	0.4	0.4
Z200S	Surface soil 182 m (200 yd) S from base of evaporated pond	0.9	a
Z400S	Surface soil 365 m (400 yd) S from base of evaporation pond	0.5	0.4
Z200N	Surface soil 182 m (200 yd) N from base of evaporation ponds	0.3	2.0
Z400N	Surface soil 365 m (400 yd) N from base of evaporation ponds	0.3	0.2
Z600N	Surface soil 550 m (600 yd) N from base of evaporation ponds	0.4	0.3
Z400E	Surface soil 365 m (400 yd) E of TP	1.0	0.5
Z200W	Surface soil 183 m (200 yd) W of TP	0.5	0.6
ZWS1	Water sediment from a stream 820 m (900 yd, N of TP	0.66	a
ZWS2	Sediment from a pool at N end of evaporated pond	a	a
ZWS3	Sediment from runoff of pool N of evaporated pond	0.80	a
ZWS4	Sediment from a stream S of evaporated pond	0.50	0.56
ZWS5	Sediment sample from ditch in field S of TP	0.51	0.50

^aNo data available for this nuclide.

4.4 Radiochemical Analysis of Water Samples

Water samples were obtained at eight locations shown in Fig. 4. These samples were analyzed using the technique described in Appendix III. The results are displayed in Table 3, which also contains descriptions of sample locations. The concentration of radium in each of the samples is below the EPA interim standard for drinking water (5.0 pCi/liter for $^{226}\text{Ra} + ^{228}\text{Ra}$).¹⁰

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

Holes were drilled at the locations shown in Fig. 5. Measurements of gamma rays as a function of depth were made by FB&DU personnel using the apparatus described in Appendix II. Since the subsurface gamma rays are due primarily to ^{226}Ra and several of its daughters, it is possible to calibrate the instrument and, thus, to convert the gamma-ray measurements to concentration of ^{226}Ra . A conversion factor may be developed by comparing gamma-ray measurements with local ^{226}Ra concentration in holes where both quantities are known. Holes at this site were drilled with hand augers, and no soil samples were obtained from these holes for analysis. Also, polyvinyl chloride (PVC) pipe was not used in the holes during the gamma radiation measurements so there is doubt as to the validity of the above-mentioned conversion.* The results of the calculation of subsurface distribution of ^{226}Ra are summarized in Table 4 instead of presented in the graphical form used in other reports in this series.

The calculated ^{226}Ra concentrations in Table 4 show a few values at the surface around 15 pCi/g; but, at the 0.6-m depth and below, few measurements are significantly above the background level. Although little significance should be attached to the absolute values of the numbers in Table 4, the data do tend to confirm the indications from

*Normally, such a pipe, sealed at one end, is used as a hole liner and the gamma-ray hole logger is lowered into the pipe. This is to insure dry conditions.

ORNL-Photo 5154-79A

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

Table 3. Concentration of ^{226}Ra in water samples

Sample designation	Sample location and description	Concentration of ^{226}Ra (pCi/liter)
ZW1	Water from a stream 820 m (900 yd) N of tailings pile (TP)	0.03
ZW2	Water from pool at N end of evaporated pond	0.07
ZW3	Water from runoff of pool N of evaporated pond	0.006
ZW4	Water from stream S of evaporated pond	0.004
ZW5	Water in ditch in field S of TP	0.05
ZW6 ^a	Water from house well ~0.8 km N of evaporated pond	0.02
ZW7 ^a	Water from house well ~1.0 km SE of TP	0.03
ZW8 ^a	Water from house well ~0.8 km SW of TP	0.06

^aZW6, 7, and 8 were taken from wells that are sampled by the Oregon State Health Department.

ORNL-Photo 5154-79B

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

Table 4. Calculated concentrations of ^{226}Ra (pCi/g) as a function of depth in auger holes at the Lakeview site

Hole	Depth below surface (m)							
	0	0.15	0.3	0.45	0.6	0.76	0.91	1.07
1	5		2	6				
2	5	<1	<1					
3	8		2		1	1		
4	14		<1		1			
5	4		<1		3	7		
6	4		4		1			
7	3		5		3	4		
8	4		7		6	<1		
9	6		<1		2	4		
10	3		1		3	<1		
11		7		1		<1		
12	16		4		2		10	
13	15		5		2		<1	
14	<1		<1		3	1		
15	7		3		4	4		
16	16		2		2		2	<1
17	2		2		4		<1	
18	3		<1		<1		2	
19	6		3		2		2	4
20	4		2		<1		<1	
21	<1		2				<1	
22	5		3		5	<1		
23	8		4		5		<1	
24	5		5		4		<1	<1
25	<1		3		<1		4	
26	4		<1		<1		2	
27	3		<1		<1		<1	
28	3		<1		2		3	
29	2		3		<1		<1	
30	4		1		2		2	

both analysis of surface soil samples and external gamma-ray measurements that a low level of contamination is present at this site.

Three soil samples were removed from a 0.5-m-deep hole dug by hand near the southeast corner of the evaporation pond area and near FB&DU hole 22 (Fig. 5). The results obtained from the analysis of these samples, using the technique described in Appendix II, are compared in Table 5 with the calculated ^{226}Ra concentration in the nearby monitored hole (Table 4, hole 22). The results of this comparison are in reasonably good agreement.

5. SUMMARY

The inactive uranium-mill site at Lakeview, Oregon, covers an area of approximately 104 hectares (258 acres), of which the tailings pile occupies 12 hectares (30 acres) in one place and 14 hectares (35 acres) elsewhere and the evaporation ponds about 26 hectares (64 acres). The tailings pile contains 118,000 metric tons of material with an estimated ^{226}Ra inventory of 50 Ci. There is an earth cover 46 to 60 cm (18 to 24 in.) thick, and it has a good vegetation cover. The gamma-ray exposure rate measurements and measured concentrations of ^{226}Ra in surface soil and sediment samples around the tailings pile and evaporation ponds, as well as the calculated ^{226}Ra concentrations in shallow auger holes, show little evidence of spread of tailings. The average gamma-ray exposure rate over the tailings pile is 16 $\mu\text{R/hr}$, and the corresponding figure for the evaporation ponds is 10 $\mu\text{R/hr}$. The latter figure is near the average background exposure rate for the area. The average exposure rate in the former mill area is 35 $\mu\text{R/hr}$.

The ^{226}Ra concentration in most surface soil and sediment samples is at or below the average background value for the region (0.8 pCi/g). The ^{226}Ra concentration in a shallow (0.5-m deep) hole dug in one of the evaporation ponds ranged from 4.1 pCi/g at the surface to the background level at the bottom of the hole.

Table 5. Comparison of measured and estimated concentrations of ^{226}Ra in hand-dug hole near hole 22

Sample designation	Depth in meters	Concentration of ^{226}Ra (pCi/g)	
		Measured	Estimated
Z4C1	0.15	4.1	5
Z4C2	0.30	1.9	3
Z4C3	0.46	1.0	α

α No gamma measurement available.

We conclude that, because of the comparatively low contamination level at this site and the apparently successful stabilization of the tailings, potential health effects of the tailings are likely to be small.

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APPENDIX I

PHASE I

Report on Conditions of Uranium Millsite and Tailings at Lakeview, Oregon

Site visited May 9, 1974 by

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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 Oregon. 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
AT LAKEVIEW, OREGON

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 at Lakeview, Oregon, was prepared jointly by the AEC, the EPA, and the Oregon State Health Division.

Summary and Conclusions

Lakeview Mining Company built and operated the mill from December 1958 to December 1960. The plant and site are now owned by Atlantic Richfield Company (ARCO) although there was a chain of ownership in between. During the period of operation 130,000 tons of ore averaging 0.15 percent U_3O_8 were treated. The 171 tons of uranium oxide produced was sold to the AEC.

The tailings are contained in one large pile covering about 35 acres. There is no cover or vegetation on the tailings pile. A small water pond on one corner is present during the rainy season. A compacted dike has been constructed out of nearby topsoil around the pile. The dike supports a fair amount of vegetation.

A gamma survey has been made in Lakeview and the vicinity of the millsite, but no contamination of tailings was determined. In addition, the State of Oregon has collected and analyzed samples of water, soil and vegetation from around the site.

At present, the main health concern appears to be the wind and water erosion of the uncovered and unvegetated tailings pile.

As a result of the site visit and review of the available information, it is concluded that a detailed further study of the site is not warranted. The following actions should be recommended to the owner of the property:

- I. Repair and strengthen the fence around the site perimeter and strengthen the entrance barricade. Post the fence with no trespassing and radiation signs.

II. Stabilize the tailings area to prevent wind and water erosion.

It is understood that since the site visit ARCO has begun millsite clean-up, tailings stabilization and fencing and posting in accordance with plans approved by the State.

Location

The property, consisting of 283 acres as shown in Figure 1, and the aerial photograph, is located in southern Oregon, in Lake County about two miles northwest of the city of Lakeview. The elevation is about 4,750 feet above sea level with mountains to the east rising to over 6,700 feet. The site covers parts of Sections 3, 4, 9, and 10, Township 39 South, Range 20 East, Willamette Principal Meridian at 42°12'43" North latitude and 120°22'09" West longitude.

Ownership

The millsite and tailings pile are owned by the Atlantic Richfield Company with operating offices in Denver, Colorado.

The operational owner of the property consisted of the same ownership as the Gunnison Mining Company of Gunnison, Colorado. In 1961 both Lakeview and Gunnison were acquired by Kerr-McGee Oil Industries through its subsidiary, Kermac Nuclear Fuels Corporation. The property has had five different owners between 1960 and the acquisition by ARCO in 1968.

Process Description

The Lakeview mill treated ores from the White King and Lucky Lass mines of southern Lake County, Oregon. Ore was from silicified volcanic rocks in the White King orebody in which uranium mineral was found as the arsenate, novacekite. In the Lucky Lass ore, the uranium occurred as autunite. The mill operated with a rated capacity of 210 tons of ore per day.

The Lakeview process included acid leaching and solvent extraction and was similar to the Gunnison operation. 1/

Present Millsite

No company personnel accompanied the survey team. Keys for the gate and buildings were obtained from the Sheriff's office. There is little control of the site other than the Sheriff and occasional checks and visits by ARCO and periodic visits by State representatives.

Figure 1. Millsite Layout and Gamma Survey of Tailings Area

Most of the mill buildings are intact, as shown in Photographs 1, 2 and 3, but some of the mill equipment has been removed. The fence around the mill is in good condition, but the gate needs to be better secured.

The 35 acre tailings pile and nearby evaporation ponds (Photograph 4) are shown on Figure 1. Dikes constructed of topsoil surround the tailings piles and ponds and support a good vegetation cover in most places. (Photograph 5). The tailings pile dike is about five feet high, but has been breached at the southeast corner. There is no cover on the 1-1/2 to over 2 feet thick tailings material except in the northwest corner where there was some water cover due to rain during the inspection visit. (Photograph 6). There is evidence of motorcycle activity on the tailings as shown in Photograph 7. The tailings are fine and dry in most places and have a tendency to migrate out of the diked area by wind erosion.

Environmental Considerations

On the basis of processing 130,000 tons of ore that averaged 0.15 percent U_3O_8 , and assuming secular equilibrium the theoretical concentration of Ra-226 in the tailings is about 420 pCi per gram of tailings. The total Ra-226 inventory in the tailings pile is estimated at 50 curies.

Gamma measurements for the tailings pond area are shown in Figure 1 and for the mill area in Figure 2.

An environmental gamma radiation survey was conducted in Lakeview, Oregon, by EPA in cooperation with the State of Oregon. 2/ As a first step, 1,345 structures were scanned by an AEC truck mounted mobile gamma unit under contract to EPA and 18 anomalies (locations with gamma levels above background) were located. After the gamma scan was completed, a field survey team checked the 18 locations to determine what caused the anomaly. At six of these locations no gamma activity greater than background could be found by the field team. At two locations increased gamma radiation was caused by ore samples or spilled ore located on the property. At the 10 remaining locations slightly elevated gamma levels were associated with brick, stone, gravel, or pavement material. No tailings materials were detected at any location. At the time of this survey, the field team made a detailed gamma survey of the millsite and tailings pile. The results of this survey are included in Figures 1 and 2. Later it was determined that the houses in the vicinity of the tailings pile had not been scanned since they are north of Lakeview and separated from the town itself. An EPA and State of Oregon field team returned to Lakeview to do gamma surveys of these locations. Twenty-six locations were surveyed and no tailings were found at any of these locations. Some of these locations were down-wind of the tailings pile and no wind-blown tailings could be detected outside of the structures with the survey meters. In addition, a motel in Lakeview was checked. A gamma reading of 25 uR/hr was found at the fence behind the motel. The source of the gamma radiation could not be determined. At the time of this survey (October 1973) a detailed

Figure 2. Mill Layout and Game Survey of Mill Area

gamma survey was conducted around the site borders of the tailings pile area. The results showed that most of the radiation at the border (as high as 95 uR/hr) was apparently caused by "shine" from the pile itself and not from any tailings deposited outside the borders. A small amount of tailings could have been deposited in this area outside the borders of the site and not be detected by the survey instruments. To determine this soil samples were collected. The results of the analysis of these samples are not available at this time. A water sample collected from the stream that flows north of the evaporation ponds contained 0.27 pCi per liter of Ra-226. The State of Oregon collected samples of water, soil, and vegetation from around the site and these samples are presently being analyzed by the State. At the time of the second survey by EPA, air samples for the determination of radon daughter levels were taken in two homes about one mile down-wind from the center of the tailings pile. These samples showed that radon daughter levels were at background levels during this sampling period. 3/

Lakeview appears to be a stable community of about 2,700 population, according to the 1970 census and being within a two mile radius of the tailings. Very few new commercial buildings or homes were noted. Most of the land between the tailings ponds and houses is pasture land.

The main industry is logging. The sawmill and associated buildings form the north border of town. None of these buildings appeared to be very new. One of the significant industrial buildings is the partially cannibalized, non-operating uranium mill building. Employment at this facility, not including mining (25 miles away), was less than 100 people when it was operating. Refer to photographs which show the present mill-site.

Meteorology

Lakeview is in a northern area with cold winters, considerable snow and moderate rainfall. Winds are mostly from the south and wind speeds are generally quite light at less than 15 mph 85 percent of the time. Occasionally there are gusts up to a maximum of about 75 mph. Freeze period is early November to late April as an average. The average annual precipitation is about 14 inches. Relative humidity averages about 58 percent.

Hydrology

The tailings pile is located in a fault-block basin in the semi-desert region of south-central Oregon. Ground water and surface water drainage is southward to Goose Lake. The lake has not overflowed since 1881 and diversion of inflow for irrigation makes overflow again unlikely. Overflow elevation is about 35 feet lower than the tailings pond, so that even if the lake filled sufficiently to cause overflow, the tailings will not be inundated.

The three largest input creeks to Goose Lake do not pose a flood problem to the tailings pond. There is an unnamed ephemeral stream in Hammersley Canyon that starts about 0.6 miles east of the pond and goes alongside and between the tailings and evaporation ponds. The canyon basin is only 3.2 square miles in area and maximum flow is not expected to exceed 67 cubic feet a second over an average of 40 cfs. It is not expected that this stream will do any dike damage, and no damage was evident.

Thermal ground water discharge occurs at Hunter Hot Springs about one-half mile north-northeast of the tailings pond and a near surface geothermal anomaly is present over an eight square mile area north of Lakeview. Most wells in the area are shallow and indicate a static water level of about 20-40 feet below the surface. Logs of wells in Sections 4 and 9 reveal alternating clay and clay/gravel sediments in the upper 800 feet of valley fill. The tailings are not believed to be saturated.

Analyses of ground water and surface water samples by the State of Oregon from around the tailings pile indicate no movement of radionuclides from the pile. Standing water nearby contained 4 and less than 2 pCi per liter of alpha beta radioactivity, respectively. Ground water from nearby wells measured about the same. Radium from one well north of the pile showed less than 0.1 pCi per liter.

It appears that adverse effects of the tailings on shallow ground water either have not occurred or have not yet been observed. It is unlikely that extensive migrations of wastes away from the ponds has occurred. Migration of radioactivity downward to deeper aquifers is improbable because of extensive clay deposits and lack of a marked downward flow gradient.

Site Visit

The site was visited on May 9, 1974, by the following personnel (team):

Robert F. Barney, Lucius Pitkin, Inc., (Contractor to USAEC),
Grand Junction, Colorado,
William L. Lappenbusch, Environmental Protection Agency,
Region X, Seattle, Washington,
George A. Boysen, Environmental Protection Agency, Office of
Radiation Programs, Las Vegas, Nevada,
George T. Toombs, State Health Division, Portland, Oregon.

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Lakeview Site - June 1974
Approximate Scale - One Inch Equals 1,250 feet.

1. West side of mill building and CCD circuit. Smell pond on tailings line.

2. Interior of mill building looking toward west wall. Note equipment still in place.

3. Mill building and sample plant. Note countryside and native vegetation.

4. View of evaporation ponds from northwest corner of tailings pile.

5. East dike of tailings pile showing vegetation and drainage ditch.

6. Drainage water in northwest corner of tailings pile and decant tower.

7. Apparent motorcycle jump in middle of tailings pond.

APPENDIX II

Soil Sampling Techniques and Radiological Measurements

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-spoon 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 μm . 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 2171-75

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 "pickie 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 Tennecomp Model TP-5/11 computer-based analyzer.

Fig. II-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.

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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 3M. 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 (3M 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. Should 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

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

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 ^{226}Ra 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.