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PROSPECTING FOR URANIUM

Published by the
UNITED STATES ATOMIC ENERGY COMMISSION
and the
UNITED STATES GEOLOGICAL SURVEY
(Revised October 1951)

Hal-fam-ite

Table 2.—THE MORE COMMON URANIUM MINERALS

[These minerals will cause the Geiger counter to react but ERALS

BLACK

Color	Name	Chemical composition	Percent ThO_2	Luster	Fluorescence	Hardness	Specific gravity	Fracture	Habit	Mode of occurrence	Remarks
Black (brownish, grayish).	Thorianite	Thorium and uranium oxide.	50–90 & 0–33% U_3O_8	Submetallic, dull, or greasy.	None	5–7					
Do	Urano-thorianite.	Uranium thorium oxide.	85 or less; & 15% or more U_3O_8	Submetallic or dull.	do	5–7					
Commonly black but extremely variable; also reddish-brown, orange, green.	Thorite	Thorium silicate.	35–70 & 0–22% U_3O_8.	Glassy when fresh; dull to greasy when altered.	do	4–5					

BROWN

Brown (yellowish or reddish); or golden or honey-yellow.	Monazite	See yellow minerals.									

YELLOW

Golden-yellow or honey-yellow; or yellowish or reddish-brown or greenish-brown.	Monazite	Cerium and rare-earth phosphate.	2–15; and 0–0.5% U_3O_8.	Resinous	None	5–6	4+		Earthy masses; thin coatings.	Scattered deposits forming irregular lenses in sandstone beds. A minor cementing agent in sandstones. Frequently associated with fossil logs and bones.	Color sometimes dulled or concealed by organic or iron staining; in such cases, pale greenish or brownish tinge.
Orange	Thorite	See black minerals.					3–4		Crystalline coatings; earthy.	Associated with calcite minerals.	Similar to carnotite.
							3		Mica-like crystals, usually small, earthy.	With other uranium minerals as coatings on many types of rocks.	A common secondary uranium mineral.

Table 1.—THE MORE COMMON URANIUM MINERALS—Continued

Color	Name	Chemical composition	Percent U_3O_8	Luster	Fluorescence	Hardness	Specific gravity	Fracture	Habit	Mode of occurrence	Remarks
YELLOW MINERALS—Continued											
Pale yellow to colorless; or dark reddish or blackish-brown; greenish-black.	Pyrochlore-microlite.	Columbium tantalum oxide.	0–15	Glassy or resinous.	None	5–6	4–6	Conchoidal, uneven, splintery, brittle.	Crystals or small grains or irregular masses imbedded in other minerals; placers.	In pegmatites, syenites, some limestones. Often associated with lithium or fluorine minerals.	Usually light in color.
Lemon-yellow, pale greenish-yellow, straw-yellow, orange-yellow.	Uranophane	Calcium uranium silicate.	65	Pearly to greasy.	None; or possibly very faint green.	2–3	4		Radiating aggregates or rosettes, finely fibrous, or less commonly massive.	In veins and pegmatites; in limestone commonly associated with other uranium minerals.	An alteration product of gummite, pitchblende, or other uranium minerals. Commonly associated with other secondary uranium minerals.
Yellow to yellow-brown.	Betafite (altered).	See black minerals.									
Yellow-green	Fergusonite (altered).	Do.									
Yellow to deep orange or brown; but color is variable.	Gummite (chiefly uranium oxide with water and lead).	Variable	40–80	Dull, waxy, greasy; occasionally glassy to brilliant.	None	2–5	4–6	Conchoidal to uneven.	Massive, dense; in crusts.	Commonly associated with pitchblende.	An alteration product of pitchblende or other uranium minerals, and usually accompanied by them; sometimes found without traces of the original minerals.
Yellow to greenish-yellow.	Schroeckingerite	Water-rich carbonate and sulfate containing uranium.	30	Pearly	Bright yellowish-green	2–3	1–2		Small, rounded masses composed of aggregates of flaky crystals; coatings.	Rounded masses distributed in gypsum-bearing sandy clay.	Occurs in Sweetwater County, Wyo.
GREEN MINERALS											
Bright green, emerald green, apple green.	Meta-torbernite (also torbernite).	Copper uranium phosphate.	60	Pearly	None; or very faint green.	2–3	3–4		Mica-like square crystals, usually small; less commonly, soft masses.	With other uranium minerals as coatings on many types of rocks.	A common secondary uranium mineral.
Apple-green, or lemon-yellow to sulfur-yellow.	Autunite	See yellow minerals									

1 dram = $\frac{1}{16}$ of an ounce

Table 1.—THE MORE COMMON THORIUM MINERALS

BROWN MINERALS

Color	Name	Chemical composition	Percent U_3O_8	Luster	Fluorescence	Hardness	Specific gravity	Fracture	Habit	Mode of occurrence	Remarks
$44.00 per dram											
Dark brown with reddish cast ("liver brown").	Euxenite	See black minerals.					9; when altered, 6.5+.	Uneven to conchoidal.	Cubes; often water-worn.	In placers; or less commonly, in pegmatites.	Sometimes has a bronze tarnish.
Do	Samarskite	Do.									
Yellowish-brown.	Brannerite (altered).	Do.									
Brown (dark reddish or blackish).	Pyrochlore-microlite.	See yellow minerals.					9+	Conchoidal	do	do	Gives a positive bead test for uranium.
Reddish-brown, deep orange, or yellow.	Gummite	Do.					4–5	do	Crystals: massive or compact.	In placers; minor amounts in granites, syenites and pegmatites.	Varieties rich in uranium are usually massive.

contains: yttrium, columbium, titanium, uranium.

YELLOW MINERALS

Canary yellow	Carnotite	Potassium uranium vanadate.	50–55	Earthy or pearly.	None	2–3					
Greenish yellow.	Tyuyamunite.	Calcium uranium vanadate.	48–55	do	None or very weak apple green.	2–3	4–5	Conchoidal to uneven; good cleavage.	Flattened or tabular crystals, usually brownish or reddish; rounded grains usually honey-colored.	In placers as rounded grains; in granites, gneisses, and pegmatites as crystals.	In placers, often associated with fluorescent zircon.
Lemon-yellow to sulfur-yellow; or apple-green.	Autunite	Calcium uranium phosphate.	60	Pearly	Brilliant yellow or apple green.	2–3					

yttrium - mentioned on page 533 of dictionary

Chapter II

WHERE TO LOOK FOR URANIUM

Prospecting for uranium will probably be most successful if carried on in areas where: (1) uranium has been found before, (2) the geologic conditions are similar to those existing where uranium has been found before, or (3) other metals have been found (especially lead, zinc, cobalt, copper, silver, nickel, bismuth, and vanadium).

The four principal types of deposit in which uranium is known to occur are as follows:

VEIN DEPOSITS

A vein is made up of minerals formed along a crack or fissure in rock. Pitchblende, the principal high-grade uranium mineral, is found primarily in vein deposits, and may occur in almost any type of rock. Where the pitchblende has been exposed to weathering, some secondary minerals are likely to be present. Two important examples of the vein type of deposit are those at Great Bear Lake, near the Arctic Circle in the Northwest Territories of Canada, and in the Katanga region of the Belgian Congo.

In the Great Bear Lake region, pitchblende is found in veins cutting across old, highly folded rocks (pri-

URANIUM MINERALS

react and will give positive bead tests for uranium]

MINERALS

Specific gravity	Fracture	Habit	Mode of occurrence	Remarks
6–9	Uneven; conchoidal.	Rounded surfaces; massive; banded.	In veins; often with sulphides of cobalt, nickel, silver, bismuth; or with yellow secondary uranium minerals.	Always black or greenish-black in thin slivers or powdered; almost never brownish or reddish.
8–10	do	Massive; in crystals.	Small amounts in pegmatites and in veins.	Always black or greenish-black in thin slivers or powdered; almost never brownish or reddish.
4–5	Conchoidal	Crystals	In pegmatites; less commonly, in placers.	Commonly altered to brown and yellow green.
4–6	do	Massive or coarse crystals; also radiating.	Nests or pockets in pegmatites.	In thin slivers or powdered, brownish or reddish.
4–6	do	do	do	In thin slivers or powdered, brownish or reddish. Similar to euxenite.
4–6	Conchoidal to uneven.	Crystals; radiating groups (rare).	In pegmatites; less commonly in placers.	Usually externally coated with buff to pinkish earthy clay-like material.
4–5	Conchoidal	Crystals; rounded grains.	In placers	Rare; known to occur in the United States only in Idaho.
2	do	Coal-like; will burn; irregular nodules.	In pegmatites	Sometimes replaces original uraninite.

Table 1.—THE MORE COMMON

[These minerals will cause the Geiger counter to

BLACK

Color	Name	Chemical composition	Percent U_3O_8	Luster	Fluorescence	Hardness
Black (grayish, greenish).	Pitchblende.	Uranium oxide.	50–80	Pitch-like, earthy, dull, or glassy.	None.	5–6
Black (grayish, greenish, brownish).	Uraninite	do	65–85	Pitch-like, dull, or glassy.	do	5–6
Black to greenish-brown.	Betafite (fresh).	Uranium columbate.	15–27	Glassy to sub-metallic.	do	4–5
Black to dark brown with reddish cast ("liver brown").	Euxenite	Rare earth titanium columbate.	1–20	Glassy when fresh.	do	5–7
Do	Samarskite	Rare earth columbate.	9–18	do	do	5–6
Do	Fergusonite (fresh).	do	0–8	Glassy	do	5–6
Jet black (brownish, greenish)	Brannerite (fresh).	Uranium titanium oxide.	40 & 4% ThO_2	Brilliant	do	4
Jet black	Thucholite	Hydrocarbon.	2–8	do	do	3–4
Black (greenish).	Pyrochlore-microlite.	See yellow minerals.				

marily metamorphosed sedimentary rocks and tuffs) in an area of fairly rugged, low-lying hills. Native silver and minerals containing cobalt, nickel, and copper are found in the veins with the pitchblende. A few secondary minerals also occur near the surface.

In Katanga, pitchblende is found in veins running through folded rocks (quartzite and dolomite) in a relatively flat, grassy region with few rock outcrops. Cobalt, copper, and nickel minerals, as well as gold, silver, and platinum, are also present. Nearly all the pitchblende near the surface has been altered into the brightly colored secondary uranium minerals.

In the mountains of western Czechoslovakia, pitchblende occurs in veins in association with silver, nickel, and cobalt. (The veins are in folded schists and dolomites.)

DEPOSITS IN SEDIMENTARY ROCKS

Certain sedimentary rocks—notably sandstones, shales, and phosphorites—may contain uranium deposits whose characteristics are unique to the type of rock in which they occur. These types of deposits, which are generally lower in grade than the vein type, are as follows:

Sandstones

Deposits of uranium in sandstones are usually spread discontinuously over comparatively large areas. In

general, they form rather well-defined ore bodies which differ considerably from each other in size and grade, and which have a spotty distribution. These ore bodies commonly contain the easily recognized, brightly colored secondary minerals.

The best known deposits of uranium in sandstone occur in the United States in the Colorado Plateau region of Colorado and Utah. For many years prior to the atomic energy program, these ores were mined for their radium and vanadium content, and are now being mined for uranium and vanadium.

In the Colorado Plateau region, uranium is found chiefly in the secondary mineral, carnotite. In some places, the carnotite occurs in sufficient amounts to color the rock a bright yellow, while in others it is present in such small quantities that it is almost indistinguishable from the buff color of the sandstone. It is associated with roscoelite and other vanadium minerals, and frequently with fossil logs and plants. Some of the ore bodies occur as small, irregular masses, and others occur as large, tabular bodies that roughly parallel the layers or beds of the sandstone.

Copper-Uranium Deposits

Several copper-uranium deposits have been found in certain shale, sandstone, and conglomerate formations of southwestern Utah and northern Arizona. The

Others

There are many other secondary uranium minerals, but most of these are very rare and, where they do occur, are usually associated with the more common minerals listed above.

radium, and uranium. It has been found chiefly in the Colorado Plateau region, where it usually occurs as soft or powdery earthy masses in sandstone. It is bright yellow, but the color may be dulled or partly concealed by organic and iron staining, giving it a pale green, gray, or brown tinge.

Tyuyamunite

This mineral is closely related to carnotite and is usually found in association with it. It has virtually the same characteristics and properties.

Autunite

This is a bright lemon to sulfur-yellow mineral. It is soft and occurs in small flat crystals through which light will penetrate, or as thin stains or coatings in rock fractures. Almost invariably it fluoresces to a bright yellow or apple green when exposed to ultraviolet light. (See Chapter III, "Testing for Uranium.")

Meta-torbernite and torbernite

These are bright green minerals. They are soft and occur in flat, square, transparent crystals, and occasionally, but not always, fluoresce to a bright green. These minerals can be distinguished from one another only by laboratory tests.

uranium occurs in a variety of minerals, but principally in torbernite and a powdery black pitchblende; the uranium minerals are generally associated with primary and secondary copper minerals. The deposits are localized and spotty, although widespread along easily recognized formations. Owing to the inaccessibility of most of this area, prospecting has been limited, and many areas in which these deposits are likely to occur still remain to be explored.

Shales and Phosphates

Deposits of uranium in shales and phosphates, like those in sandstones, occur over wide areas. However, unlike the sandstone deposits, they are usually spread continuously throughout an entire layer or bed and have a rather uniform grade and thickness. Few of the uranium-bearing minerals in shales and phosphates can be recognized in the field. For this reason, such deposits usually can be found and followed only with the Geiger counter (see Chapter IV, "Prospecting with the Geiger Counter"), or by taking samples for chemical assay. In a few places, traces of the brightly colored secondary uranium minerals may occur as stains or coatings in cracks on or exposed surfaces.

Deposits of this type are usually much lower in grade, though more continuous, than the carnotite deposits of the Colorado Plateau. Deposits in shales have been

found in Sweden, the Soviet Union, and in the United States in Tennessee, and deposits in phosphates have been found in Idaho, Montana, and Florida.

PLACER DEPOSITS

Placers are deposits of sand and gravel which contain one or more valuable minerals. They usually occur along rivers and beaches. The minerals in placers are those which have been moved from their original point of deposit—as solids, not as solutions—and concentrated as a result of their high specific gravity and resistance to decomposition processes. Since most uranium minerals are not resistant to decomposition, they are rarely found in significant amounts in placers. Thorium minerals, however, are frequently found in placers, and some of these—particularly thorianite and thorite—may contain some uranium as well as thorium.

Since the uranium and thorium minerals occurring in placers are difficult to distinguish from the other minerals present, the best means of detecting them is the Geiger counter.

PEGMATITE DEPOSITS

Pegmatites are coarse-grained, light-colored rocks commonly occurring as large, vein-like deposits which are associated with granite or other granitic rocks. The primary constituents are similar to those of granite,

not occur in large enough concentrations to be considered as significant sources of uranium. Most of the columbates and tantalates are refractory minerals, and although they have been mined for uranium on a limited scale in some parts of the world, it is costly to extract the uranium from them. These minerals, which usually occur in irregular masses of well-formed crystals, range in color from dark brownish red to black. In thin slivers or when powdered, they are decidedly reddish or reddish brown, which distinguishes them from powdered pitchblende. They are also less pitch-like than pitchblende, and are found for the most part in pegmatites.

SECONDARY URANIUM MINERALS

Secondary uranium minerals are usually characterized by bright yellow, orange, and green colors, and usually occur as earthy or powdery masses, as groups of very small crystals, or at flat plates. The secondary minerals may occur in almost any type of rock, and may or may not be associated with primary minerals. The principal secondary minerals, which all have a lower percentage of uranium than pitchblende, are as follows:

Carnotite

This mineral has been commercially important in the United States for many years as a source of vanadium,

in the Belgian Congo, Canada, and Czechoslovakia. It usually is found in vein deposits, frequently in association with the sulphide minerals of such metals as silver, cobalt, nickel, iron, lead, zinc, bismuth, and copper. It occurs in rounded, irregular masses, rather than as crystals, and breaks with a curved surface as does glass. Pitchblende is heavier than iron, about as hard as steel, and is grayish black, sometimes showing a greenish cast. It is practically never brownish black or reddish brown as are many of the other primary uranium minerals. When crushed into thin fragments or ground to a powder, pitchblende is always black, greenish black, or grayish black.

Uraninite

This mineral has the same color, as well as most of the other properties and characteristics of pitchblende. Unlike pitchblende, it occurs in the form of small, cube-shaped crystals, rather than as rounded, irregular masses. It is sometimes found in association with pitchblende, but is most likely to be encountered in pegmatites.

Others

The other primary minerals are the uranium-bearing oxides of columbium, tantalum, and titanium, such as betafite, euxenite, and samarskite. In general, they do

except that they usually occur in much larger crystals. Pegmatites may also contain commercial amounts of many of the rare minerals.

Very small amounts of most of the primary uranium minerals, including uraninite, betafite, euxenite, fergusonite, and samarskite, occur in pegmatites. The minerals are found as small nests or pockets scattered through the rock, and frequently display well-formed crystal faces. Most of these minerals can be identified by the characteristics given in table I.

Although in various parts of the world, some uranium has been mined on a small scale from pegmatities, most pegmatites investigated to date have carried such a small amount of uranium that it has not been practicable to mine them for the uranium minerals alone.

?

Chapter III

TESTING FOR URANIUM

There are various tests that can be applied by prospectors to aid in determining whether or not a mineral or rock contains uranium. These tests, which all involve either fluorescence or radioactivity, are as follows:

FLUORESCENCE

Minerals that are fluorescent will glow when exposed to ultraviolet light. This light, sometimes called "black light," is produced by special lamps sold by a number of different companies. They operate on batteries or on regular electric current, and should be used in darkness.

The use of fluorescence as a means of distinguishing uranium minerals in their natural state is limited, since only one important uranium mineral, autunite, always fluoresces. Other uranium minerals that fluoresce are extremely rare. Two of the most important uranium minerals—pitchblende and carnotite—never fluoresce in their natural state. On the other hand, many minerals such as scheelite (a tungsten mineral) *do* fluoresce, and yet do not contain any uranium and are not related to uranium in any way. In addition, the very common mineral calcite, which does not contain uranium, occasionally fluoresces.

CLASSIFICATION OF URANIUM MINERALS

Uranium minerals are divided by geologists generally into (at least) two classes: primary and secondary. Most primary uranium minerals are those that have been formed by heated solutions coming up from deep within the earth. Secondary minerals are those that have been formed by changes in primary minerals brought about through the action of weathering, ground waters, or by other natural processes.

PRIMARY URANIUM MINERALS

Primary uranium minerals are usually found in vein deposits or pegmatites. (See Chapter II, "Where to Look for Uranium.") They are generally dark brown or black, are noticeably heavy, with a specific gravity of four or more, and frequently have a dull, pitch-like luster. They are not commonly found in surface rocks exposed to weathering. The more important primary uranium minerals are as follows:

Pitchblende

This is by far the most important uranium mineral. It is essentially uranium oxide, and is the chief constituent in virtually all high-grade uranium ore. Pitchblende has been the source of major uranium production

Mineral	Pages	Chemical composition
Autunite	6, 10, 12	Calcium uranium phosphate.
Betafite	5, 8, 12	Uranium columbate.
Brannerite	8, 10	Uranium titanium oxide.
Carnotite	6–10	Potassium uranium vanadate.
Euxenite	5, 8, 10	Rare earth titanium columbate.
Fergusonite	8, 12	Rare earth columbate.
Gummite	10, 12	Variable, chiefly uranium oxide with water and lead.
Meta-torbernite	6. 12	Copper uranium phosphate.
Monazite	14	Cerium and rare earth phosphate.
Pitchblende	4, 5. 8	Uranium oxide.
Pyrochlore-microlite	8, 10, 12	Columbium tantalum oxide.
Samarskite	5, 8, 10	Rare earth columbate.
Schroeckingerite	12	Water-rich carbonate and sulfate con taining uranium.
Thorianite	14	Thorium and uranium oxide.
Thorite	14	Thorium silicate.
Thucholite	8	Hydrocarbon.
Torbernite	6, 12	Copper uranium phosphate.
Tyuyamunite	6, 10	Calcium uranium vanadate.
Uraninite	4, 8	Uranium oxide.
Uranophane	12	Calcium uranium silicate.
Uranothorianite	14	Uranium thorium oxide.

Although most uranium minerals will not fluoresce in their natural state, the property of fluorescence can be used to detect the presence of uranium in a chemical test known as the "bead test," described below.

Bead Test

To make a bead test, the following items are required:

1. A small sample of finely ground mineral or rock.
2. A piece of wire (iron wire may be used) bent into a loop (about ¼ inch in diameter) at one end.
3. Means for producing a small, fairly hot flame, such as an alcohol lamp or a Bunsen burner.
4. Lithium fluoride or sodium fluoride (dry compounds available from any chemical supply house).
5. A source of ultraviolet light.

When these materials have been assembled, the loop of wire should be dipped into the sodium or lithium fluoride and heated over the flame until a bead (a small molten drop) is formed. Then the bead should be brought into contact with the ground rock sample, so that one or more grains from the sample are attached to it. The loop end of the wire should then be held over the flame until the grains are melted into the bead. After the bead has cooled, it should be examined under ultraviolet light in a darkened place. If any uranium is present the bead will fluoresce to a bright yellow green.

The bead test is an effective means of identifying uranium. It will work with all important uranium minerals, including those that do not fluoresce in their natural state. It is sensitive enough to indicate the presence of minute amounts of uranium (as little as 0.05 percent U_3O_8) in a rock and is effective in determining which of the many minerals in the rock contains uranium. It is also simple enough to be readily used by prospectors in the field.

The bead test, however, has certain limitations. For example, it will not work if the mineral being tested contains a large amount of such rare earth elements as thorium and cerium. Consequently, it cannot be used to test monazite or allanite even if these do contain small quantities of uranium. Another limitation is the fact that minerals containing tungsten will fluoresce when treated with lithium fluoride (but not with sodium fluoride), and minerals containing columbium will fluoresce when treated with sodium fluoride (but not with lithium fluoride). The fluorescence produced by these elements, however, is generally weaker than that produced by uranium, and is distinctly bluish. Because of its limitations, the bead test is most effective when combined with a test involving radioactivity (see page 25).

Chapter I

THE URANIUM-BEARING MINERALS

The element uranium never occurs in its pure form in nature. Instead, it is always combined with other substances to form a mineral. More than 100 uranium-bearing minerals are known to exist. In some of these uranium is the chief constituent, but in others it forms only a very small part of the whole.

From the standpoint of the prospector, it is desirable to have knowledge of all the more common uranium minerals, whether or not they may serve as commercial sources of uranium, because where one such mineral is found, others are likely to occur nearby. The most common uranium minerals, as well as the most common thorium minerals, together with their chief identifying characteristics, are listed in the tables on pages 8 to 15. An alphabetical listing, with the page reference and the chemical composition, of these minerals follows:

FOREWORD

Uranium is today the only naturally occurring substance that can be used as a basic raw material in the large-scale production of atomic energy. For this reason, the United States Atomic Energy Commission, in April 1948, established a guaranteed minimum price schedule designed to stimulate the discovery and production of uranium within the United States and its possessions and territories.

As a result of this action, thousands of inquiries have been received by various Government agencies from prospectors and other interested persons wishing to obtain information on all phases of the occurrence, identification, and sale of uranium-bearing ores. This booklet attempts to answer, in brief form, as many of these questions as possible. Since the general prospecting methods used in searching for uranium are the same as for other minerals, the booklet does not attempt to cover such subjects as general equipment and general prospecting procedures. Those who wish more detailed information on these subjects are referred to the list of publications in appendix 1.

Neither does the booklet make any attempt to provide more than the most general information on thorium, which is a potential source of atomic energy. So far, commercial production of monazite, a rare earth phosphate and the principal ore of thorium, has come almost entirely from deposits of heavy mineral sands which occur in beach or stream placer deposits.

Domestic rare earths producers are licensed by the Commission to purchase monazite sands, for which there is an active market at present. The thorium produced in connection with recovery of rare earths is available for purchase by the Commission.

RADIOACTIVITY

One of the principal characteristics of uranium ores and minerals by which they can be identified is their universal property of radioactivity. This means that they all emit certain rays, or radiations, that cannot be seen, heard, or felt, and which can only be detected by means of special instruments. In making radioactivity tests for uranium, however, it should be remembered that there are other elements, notably thorium, which are also radioactive. It is not possible to distinguish between the radiations emitted by the minerals of thorium and uranium except in a laboratory where careful scientific tests can be made. Another important fact is that there is no simple field test that will show the exact amount of uranium present in a sample of mineral or rock. Precise assays of the uranium content of samples can only be made in the laboratory. How prospectors may have laboratory assays of samples made is described in chapter V.

Following are the principal tests that may be used to determine whether a rock sample is radioactive:

Photographic Test

This relatively simple test makes use of the fact that rays from a radioactive mineral will blacken an unexposed photographic film in much the same manner as sunlight does. The test is made by first wrapping a

strip of unexposed camera film (or plate) in black photographic paper (or other heavy light-resistant paper) in such a way that no light can penetrate to the film. Then a key or other small metallic object is placed on the wrapped film, and the rock sample to be tested is placed on top of this. If the sample contains uranium or other radioactive elements, the rays given off will darken the film, giving an image, called a "radiograph," of the key when the film is developed. For best results, the bottom of the sample should be flat and fairly smooth.

In the photographic test, the sharpness of the image produced on the developed film, together with the exposure time required to produce the image, will provide a rough measure of the amount of radioactive material contained in the sample. A specimen of pitchblende will produce a clear image in 1 day, but low-grade uranium minerals may require several weeks to produce similar results. In comparing the radioactivity of different samples, equal exposure times should be used, or a record should be kept of the length of time required to produce the image in each case.

Scintillation Test

When the rays from radioactive materials strike a screen coated with zinc sulphide powder, they produce bright flashes of light known as "scintillations." These

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flashes may be observed by using a tube-shaped instrument called a "scintilliscope," which consists of an eyepiece with a magnifying lens and a zinc sulphide screen. If a strongly radioactive mineral is held near the screen, flashes of light can be seen through the eyepiece. The instrument should be used in a dark place, and only after the observer's eyes have become thoroughly adjusted to the darkness. Scintilliscopes are useful in detecting strongly radioactive materials. They do not always show weak or moderate radioactivity, however, and are not helpful in measuring the amount of radioactive material contained in an ore sample.

Electroscope Test

This test utilizes an instrument known as an "electroscope," which looks like a glass bottle and has two narrow, very thin metal strips hanging from a metal plug in the neck of the bottle-like container. The metal strips, which are called leaves, are usually made of gold. Electroscopes are sold by many firms dealing in scientific instruments and are not expensive.

When an electric charge is put on the leaves of an electroscope, the leaves fly apart. This charge is applied by rubbing a glass or plastic rod with a woolen cloth, and then touching the rod to the top of the electroscope's metal plug. The charge flows down the plug to the leaves, and the leaves swing away from

each other. If, at this point, a radioactive mineral is brought near the metal plug of the charged electroscope, the rays from the mineral will discharge the instrument. In other words, the leaves that have been apart will fall together again—rapidly if the mineral is strongly radioactive, slowly if it is weakly radioactive.

Electroscopes are not very well suited for use in the field because they cannot stand rough handling and are affected by changes in weather. The electroscope is primarily a laboratory instrument.

Geiger Counter Comparison Test

The instrument used in this test, the Geiger counter, is discussed at greater length in the succeeding chapter. The test gives a rough assay of the uranium content of a sample of mineral or rock. In making the test, it should be remembered that a Geiger counter cannot distinguish between the radioactivity of uranium and the radioactivity of such other radioactive elements as thorium. For this reason, the fact that a sample contains uranium, and not thorium, should be definitely established by some other means, such as the bead test.

To make a Geiger counter comparison test, the items needed are a Geiger counter, a sample to be tested, and a sample in which the uranium content is known. The New Brunswick Laboratory of the Atomic Energy Commission has for sale standard samples which may

Myrl J. Creel.

PROSPECTING FOR URANIUM

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Chapter VII

QUESTIONS FREQUENTLY ASKED

The U. S. Geological Survey and the U. S. Atomic Energy Commission receive hundreds of letters every week asking questions relating to uranium prospecting and mining. The questions most frequently asked are answered specifically below:

QUESTION: *Where may I obtain samples of uranium minerals to study before I begin prospecting?*

ANSWER: Samples of uranium minerals (not of pure uranium) may be bought from mineral dealers. Also, many museums in the larger cities display specimens in their mineralogical exhibits. Among the mineral dealers from which samples of uranium minerals can be purchased are:

Grieger's
1633 East Walnut Street
Pasadena 4, Calif.

V. D. Hill
Route 7, Box 188
Salem, Oreg.

A. D. Mackay
198 Broadway
New York 7, N. Y.

be used for this purpose. These samples have been ground to a fine powder and tested carefully for their uranium content. Instructions as to how they may be obtained appear on page 55. The Geiger counter comparison test is made as follows:

1. Place the counter on a table or some other flat surface.
2. Take and record the background reading. (See Chapter IV, "Prospecting With the Geiger Counter.")
3. Place the known sample of uranium ore close to the probe of the counter and note and record the reading.
4. Remove the known sample and place it far enough away that it no longer affects the counter.
5. Place the unknown sample of ore in exactly the same position with respect to the counter probe as the known sample was placed, and note and record the reading. For best results, the unknown sample should be approximately the same size as the known sample.
6. Subtract the background reading from the readings obtained on the known and unknown samples, and compare the resultant figures. These provide a basis for computing roughly the uranium content of the unknown sample.

Chapter IV

PROSPECTING WITH RADIATION DETECTION INSTRUMENTS

The most practicable instruments so far devised for detecting radioactive materials in the field are the Geiger-Mueller counter, generally called simply the "Geiger counter," and the scintillation counter. Battery-operated, portable models of the "Geiger counter" are already popular among prospectors, and are available from a large number of commercial manufacturers and distributors. A partial list of such companies is included in appendix 2.

A portable Geiger counter is somewhat similar, in a general way, to a small, battery-operated radio. It consists principally of a glass or metal tube, a circuit and batteries. When a radioactive substance is near the counter tube, the rays from the substance produce pulses of electric current in the tube which are recorded either as clicks in earphones or as readings on a meter, or both. The number of pulses per minute is called the "count," which is a measure of the strength of the radioactivity to which the instrument is being exposed.

The most complete Geiger counters for prospecting include a carrying case and strap, a probe (containing

sold or transferred to licensed buyers or delivered to the Atomic Energy Commission for its guaranteed minimum prices. As in the case of claims located on public lands, the Government reserves the right to enter and mine the ore, or to require delivery if it deems this to be necessary. These rights, however, do not apply to certain plots of less than 1 acre which are devoted primarily to residential use.

Inquiries arising in connection with formerly Government-owned lands other than public lands leased or purchased since December 5, 1947, should be addressed to the agency which sold or leased the property or to the U.S. Atomic Energy Commission, Washington 25, D. C.

a reservation of the right of the United States to enter on the lands and mine and remove the uranium or thorium deposits of the leased lands.

From March 4, 1946, through December 4, 1947, sales or leases of Government-owned lands other than public lands were permitted, but the person purchasing or leasing these lands generally received no rights in any uranium or thorium deposits contained in the lands sold or leased, and the Government reserved the right to enter and remove deposits. Inquiries relating to Government-owned lands other than public lands sold or leased from September 13, 1945, through December 4, 1947, should be addressed to the agency which sold or leased the property.

Government-Owned Lands Other Than Public Lands Leased or Purchased Since December 5, 1947

Under Executive Order No. 9908 (see appendix 6) the present owner (or lease-holder) of Government-owned lands other than public lands sold by the Government after December 5, 1947, has the same rights to uranium or thorium deposits on his land as a locator who has staked a claim on public land after August 1, 1946, unless the lands were sold or leased subject to a reservation of all minerals. In other words, the uranium in these lands may be worked or leased in the same way as any other mineral deposits, and the ores removed may be

the tube), a meter for registering the number of pulses visually, and an adjustable sensitivity scale. Most models also have earphones. The amount of equipment provided varies with different manufacturers and different models, and prospective purchasers for this reason should study the various catalogs carefully. Most manufacturers supply instructions for the efficient use of their instruments.

SCINTILLATION COUNTERS

Scintillation counters have been used for some time in the laboratory, and it is only recently that portable instruments suitable for prospecting have been developed. Scintillation counters have two basic parts: a crystalline material which converts the radiation into visible light and a photoelectric unit with a meter circuit which enables the operator to note the presence of radioactive materials.

Various other radiation detection instruments suitable for field work are being developed. Airborne and carborne Geiger and scintillation counters and instruments suitable for detecting radioactivity in drill holes give most promise of being useful. At present, however, the Commission does not have a reference list of dealers in such instruments available for distribution.

THE BACKGROUND COUNT

When using the Geiger counter, it is important to remember that the instrument will record a relatively small number of pulses even when it is not near uranium minerals or other radioactive material. These pulses are called the "background count." They are caused mainly by cosmic rays and partly by minute quantities of radioactive elements that are present in nearly everything on earth. The background count varies according to the sensitivity of the counter, and according to the topography and geology of the area. In general, the background count will be higher over some rocks (for instance, granite) than others (basalt and limestone). Background in most tunnels or mine workings is higher than surface background.

In prospecting with the Geiger counter, the first step should be to record the background count for the general area under observation. No count on any sample or deposit is significant until the background count for the general area is established.

Background counts are determined by taking readings of 1, 2, or 3 minutes' duration at various times during the day and at locations well removed from the vicinity of the suspected deposit. The average of these readings gives a fair indication of the background count for the area. In making background readings, it is im-

night, July 30, 1946, except in some cases where the amount of uranium or thorium was not substantial. Inquiries as to the validity of an individual claim believed to have been located between September 13, 1945 and July 30, 1946, should be addressed to the Bureau of Land Management, Department of the Interior, Washington 25, D. C.

Public Lands Leased Between March 4 and July 30, 1946

Public lands containing substantial amounts of uranium or thorium were subject to lease under the leasing laws during the period between March 4 and July 30, 1946, but all mineral leases issued were required by Executive Order No. 9701 to contain a reservation to the United States of all uranium or thorium deposits in the land, and a right in the Government to enter, prospect for, mine, and remove these deposits.

Government-Owned Lands Other Than Public Lands Leased or Purchased Between September 13, 1945, and December 4, 1947

From September 13, 1945, through March 3, 1946, Government-owned lands other than public lands (known usually as acquired lands) generally could not be sold, because of Executive Order 9613, then in force, if they contained deposits of uranium or thorium ores. Leases of Government-owned lands, other than public lands, made during that time were required to contain

dures") apply to ores removed from claims located on the public lands after August 1, 1946.

EXECUTIVE ORDERS

Three Executive orders have been issued by the President since September 13, 1945, which affect the rights to uranium or thorium of persons who staked certain claims or who now lease or own certain classes of land formerly owned by the Government. Most prospectors and miners will not be affected by the provision of these Executive orders. The claims and lands which are affected are described below:

Claims Staked Between September 13, 1945, and July 30, 1946

On September 13, 1945, by Executive Order No. 9613, the President withdrew from entry all vacant and unappropriated public lands which contained deposits of radioactive mineral substances. On March 4, 1946, by Executive Order No. 9701, these lands were generally reopened for entry under the nonmineral land laws, but entries under the mining laws were still not permitted until the effective date of the Atomic Energy Act, August 1, 1946, which qualified the terms of Executive Order No. 9701. As a result, no valid mining location could be staked on public lands containing uranium or thorium ores from September 13, 1945, through mid-

portant to remember that background counts are not only different in different places, they are different in the same place at different times. For this reason, a new background count should be made every hour or so while the counter is in continuous use or each time a specific test is made.

GENERAL RECONNAISSANCE

After having first determined the background count for a general region, the prospector may proceed by merely walking with his Geiger counter over the area in which he is interested, meanwhile taking into account the general topography and geology of the land. At any place where the counter registers two or three times the background count, a close examination should be made with the counter probe in order to determine the precise source of the radioactivity. In particular, the prospector should try to determine whether the radioactivity is coming from a high-grade vein or from a mineral sparsely distributed through the rocks, since a relatively large area of weakly radioactive rocks will cause a response similar to that of a small crevice filled with high-grade ore.

It is not possible to say what minimum reading a counter should give to indicate acceptable quantities of grades of uranium ore. A specific area that consistently gives readings of more than several times the back-

ground may well prove to be significant. The main thing is to obtain the reading in a specific area in terms of the background, and to select representative samples of the rock for assay. If the radioactivity of any particular rock is four times the background count, a sample should be taken.

In prospecting with the Geiger counter, it is important not to cover ground too rapidly. Otherwise, the counter may not have time to register narrow veins that might be passed over. It is good practice to pause and take 1-minute readings at frequent intervals, especially in areas where preliminary testing indicates that radioactive minerals may be present. The readings should be taken by placing the counter probe on the ground.

The question of how close a Geiger counter must be brought to uranium-bearing minerals in order to detect it cannot be answered in terms of feet or inches. A counter's ability to detect a uranium deposit depends primarily upon four factors: the amount of radioactive ore, the richness of the ore, the amount of overburden, and the distance of the counter from the surface. The depth of overburden that rays from a radioactive mineral can penetrate depends upon the type of overburden. In some cases as little as 6 inches will conceal the presence of uranium minerals. Naturally, high-grade ore will produce stronger rays than low-grade ore,

uranium or thorium protects the Government from, among other things, a claimholder's refusal to work a deposit.

Under the provisions of the Atomic Energy Act, the Atomic Energy Commission may also, if it considers it necessary, require the delivery to the Commission of uranium or thorium, located on public lands after August 1, 1946, after the metal has been mined and separated. If the Commission exercises this power, it must pay the reasonable value of their services, including a profit, to those persons found by the Commission to have performed services in the discovery, mining, and extraction of the metal. It does not have to pay for the uranium or thorium.

Up to the present time, the Commission has not thought it desirable or necessary to exercise either of these rights, and it will not be the policy of the Commission to exercise them except in case of emergency where no other course of action is practicable. It is not expected that such an occasion is likely to arise.

In preference to exercising its right of entry or its power to require delivery, the Commission follows the policy of acquiring ores or concentrates through ordinary commercial means. Accordingly, the guaranteed minimum prices established by the Commission (see Chapter V, "Laboratory Assays and Selling Proce-

example, in the carnotite areas of western Colorado, a valid claim, which may be reduced to patent, may be based on either the uranium or the vanadium content of the ore or on both metals.

The standard procedures for staking claims on the public lands of the United States and Alaska are outlined in Circular No. 1278 of the Bureau of Land Management. (See appendix 5.) The rules stated there are applicable to uranium and thorium ores.

GOVERNMENT RIGHTS AND POWERS

Because of the provisions of the Atomic Energy Act, the Government keeps certain rights in uranium or thorium ores located on public lands after August 1, 1946. The most important of these is the right of the Atomic Energy Commission to enter on the land subject to the location and remove the uranium or thorium ore. If this right of entry is used, the Commission is required by law to compensate the locator for the damage or injury caused by its action, although not for the uranium or thorium which is removed. For example, in the case of a carnotite deposit, the Commission would be required to pay the claim holder for the vanadium which would be removed along with the uranium, but not for the uranium content of the ore. This right of the Commission to enter and remove ores which contain

and therefore may be detected at a greater depth beneath the earth's surface. Even high-grade ores, however, can rarely be detected under more than 2 feet of overburden.

THE GRID SURVEY

Once it has been established that a definite area is radioactive, it may be studied in more detail by means of the "grid survey." In this case, the area under investigation is marked off in squares about 20 feet to a side, and a map of the area is outlined with corresponding lines. One-minute readings are taken at the corners of the squares by placing the counter probe on the ground, and the readings are noted on the map in their proper locations. When readings have been taken over the entire area in this manner, lines are drawn on the map connecting the points of greatest radioactivity. Then lines are drawn connecting the points of next greatest radioactivity, and so on until all parts of the area showing above-background radioactivity are outlined. The map will then indicate roughly the extent, shape and variation in grade of the deposit. More than one such survey may have to be made before valid results are obtained. It is also desirable to note any points of particularly high activity that are encountered between the corners of the grid.

In making a grid survey, it is important that the

background count be subtracted from the readings in order to give them meaning. In this case, the background is always obtained by taking a number of readings *off* the area of interest and averaging them together.

CARE OF THE COUNTER

Most Geiger counter field units are built to stand a normal amount of rough handling, but the counter is a precision instrument and should be protected as much as possible from abuse. A few simple rules that will lengthen the life of the average Geiger counter are as follows:

1. Always carry it in a waterproof canvas case to avoid direct contact with water.
2. Do not use it in an excessively humid environment, such as a wet mine, unless it has been "tropicalized." Humid conditions destroy the internal insulation and shorten the life of the tube. Sometimes only an hour or two of operation under these conditions will severely damage the instrument. Some manufacturers will tropicalize their counters, thus making it possible to use them in places when dampness or humidity is constant.
3. Do not use it in very cold weather. Many counters do not work well in freezing temperatures, and may fail to operate at all.

effective, is reserved "for the use of the United States." It is the view of the Atomic Energy Commission and the Department of the Interior, however, that this provision does not prevent the staking of a valid claim as a result of the discovery of uranium or thorium, and will generally not prevent the locator from mining or selling the ore.

STAKING CLAIMS

If a citizen, or a person who has declared his intention to become a citizen, discovers uranium or thorium on the vacant and unappropriated public lands, he may stake a claim in exactly the same way as for copper, gold, or any other valuable metal.

Many uranium-bearing or thorium-bearing ores also contain other valuable metals. In these cases, a valid claim may be staked on the basis of the discovery of the whole ore, or of any metal or combination of metals that may have commercial value. As a rule, it is not necessary for the locator to name in the location certificate the valuable metal upon which his claim is based.

He may merely state that the claim contains "valuable minerals." Where he desires, or is required, to name a specific metal in a location certificate or application for patent, it is permissible for him to use uranium or thorium as the basis for his claim, or if he desires, to specify any of the other valuable metals or combination of metals that are present in the ore. For

Alaska, Organ Pipe Cactus National Monument in Arizona, and Death Valley National Monument in California. Mining locations may not be made on lands in any other national park or monument.

The Atomic Energy Commission, in cooperation with the U. S. Geological Survey, is carrying on diamond drilling and geological surveys on certain public lands in the Colorado Plateau area and elsewhere. In order to aid this official exploration program, the Department of the Interior, under the public land laws, has withdrawn from entry and appropriation approximately 150 square miles of public land in southwestern Colorado and southeastern Utah. These withdrawn lands are described in Public Land Orders 459, 494, 565, and 698. Lands covered by these orders on which further exploration is not planned will be released from the withdrawal orders and again will be open for entry. It is expected that lands found to contain uranium will become available for development and mining by private interests under arrangements with the Commission.

The principal difference between prospecting for uranium and thorium ores and prospecting for other metallic ores on public lands arises from the Atomic Energy Act, which provides that all uranium and thorium on those public lands which were vacant and unappropriated on August 1, 1946, when the act became

4. Do not overheat it. Placing the counter too near a campfire, for example, will destroy the batteries. (When on an extended prospecting trip, it is always advisable to carry an extra set of batteries.)
5. Do not place it in a carrying case with ore samples. The counter must be protected at all times from contamination by radioactive dust and dirt.
6. Except for changing batteries, do not attempt to repair it yourself unless you have had technical training in electronics. If replacing the batteries does not correct the difficulty, return the counter to the dealer or manufacturer.
7. Do not allow it to register radioactivity so rapidly that individual clicks cannot be distinguished or that the meter hand swings off the dial. This is harmful to the counting mechanism. When this occurs, the counter should be adjusted to a less sensitive position or the distance from the material producing the radioactivity should be increased.

Chapter V

LABORATORY ASSAYS AND SELLING PROCEDURES

When a prospector believes that he has discovered a uranium deposit he should first test samples of the rock as carefully as he can with his own equipment. If the samples show promise, he should have them tested by a commercial assayer or by a Government agency. Professional assaying services are provided by a large number of private firms throughout the country. In addition, the U. S. Geological Survey, the U. S. Bureau of Mines, and some State mining and geological agencies will examine samples for uranium or thorium without charge.

SENDING SAMPLES FOR ASSAY

Samples submitted to the U. S. Geological Survey should be addressed as follows:

U. S. Geological Survey
Geochemistry and Petrology Branch
Building 213, Naval Gun Factory
Washington 25, D. C.

Samples submitted to the U. S. Bureau of Mines should be addressed to one of the following:

thorium or any combination thereof. A license may be issued to authorize a single transfer or continuing transfers.

Licensing regulations do not apply to very limited movements of uranium or thorium which do not involve the transfer of control, possession, or title to another person, firm, or corporation. This means, for example, that a company owning several mines may collect and move ore from these mines to a central stock pile on its own property without obtaining a license from the Commission.

PUBLIC LANDS

The vacant and unappropriated public lands (including lands in national forests, except those acquired under the act of March 1, 1911, known as the Weeks Act, and other repurchased lands) in the States of Arizona, Arkansas, California, Colorado, Florida, Idaho, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming, and the Territory of Alaska, are open to prospectors for uranium and thorium, and a valid claim based upon the presence of these metals may be located.

Certain national monuments and one national park are also open to prospectors. These are Mt. McKinley National Park and Glacial Bay National Monument in

owner of the land or mineral rights is needed. In the case of State lands, this will be the State government.

On Indian Reservations, a permit to prospect for any type of ore must be obtained from the superintendent of the reservation. If a discovery is made, an application for a lease may be sent to the Bureau of Indian Affairs, Department of the Interior, Washington 25, D. C. There is one exception to this rule: no permit is needed to prospect on the Papago Indian Reservation in southern Arizona, although the locator must furnish the superintendent with a copy of his location notice within 90 days after filing.

No license or permit is needed to lease or purchase mining rights to uranium or thorium in privately owned lands or in locations on the public domain. Arrangements for the lease or purchase of mining rights for these metals may be made between persons in the same manner as if the lands contained no uranium or thorium.

A license from the Atomic Energy Commission *is* needed to sell, transfer, or receive uranium and thorium ores which have been removed from the ground, no matter where or when they were mined. The procedures for obtaining this license, which are simple to follow, are included in a regulation issued by the Commission. (See appendix 4.) The ores subject to licensing—called "source materials"—are those that contain by weight 0.05 percent or more of uranium or

Chief, College Park Branch
Metallurgical Division
U. S. Bureau of Mines
College Park, Md.

Chief, Rolla Branch
Metallurgical Division
U. S. Bureau of Mines
Rolla, Mo.

Chief, Salt Lake City Branch
Metallurgical Division
U. S. Bureau of Mines
Salt Lake City, Utah

Chief, Tucson Branch
Metallurgical Division
U. S. Bureau of Mines
Tucson, Ariz.

Chief, Albany Branch
Metallurgical Division
U. S. Bureau of Mines
Albany, Oreg.

Chief, Tuscaloosa Branch
Metallurgical Division
U. S. Bureau of Mines
Tuscaloosa, Ala.

Supervising Engineer
Metallurgical Division
U. S. Bureau of Mines
Reno, Nev.

Samples submitted to the Geological Survey or the Bureau of Mines should weigh at least 1 pound, should be carefully wrapped in a strong package, and should be clearly labeled with the sender's return address. If more than one sample is submitted in the same package, each sample should be numbered. Each sample should also be a representative one; that is, it should represent, as fairly and as accurately as possible, the rocks of the entire deposit from which it was taken. If one part of the deposit appears to be more radioactive than another, rocks taken from both parts should be included in the sample. If a small amount of high-grade ore is submitted, it should be stated that the sample is not representative of the entire deposit, but only of a small portion of it.

The results of assays performed by the Geological Survey and the Bureau of Mines are reported to the individual submitting the sample and to the Atomic Energy Commission if the sample shows radioactivity.

When samples are submitted to a Federal agency for assay, it is desirable to include the following specific information with each sample:

Chapter VI

LAWS AND REGULATIONS

The Federal, State, and local prospecting and mining regulations which apply to metallic ores generally, also apply to the uranium-bearing and thorium-bearing ores. Because uranium and thorium ores can be used as source materials in the production of atomic energy, they are also subject to certain other controls which stem from provisions of the Atomic Energy Act, effective August 1, 1946. (See appendix 6.) These special controls, however, apply for the most part to the sale or transfer of uranium and thorium ores after they have been removed from the ground, and generally will not interfere with normal prospecting and mining operations. Actually, it is the policy of the Federal Government to encourage, rather than to restrict, the independent prospecting for and the independent mining, processing, and sale of uranium.

LICENSES

No Federal Government license or permit is needed to prospect for or mine uranium or thorium on public or private lands, except in those places, such as certain Indian Reservations, where prospecting or mining permits are required generally. In order to prospect on State or privately owned lands, the permission of the

Licenses are issued automatically for delivery of ores to these purchase depots and to the Commission's purchase depots at Monticello and Marysvale, Utah.

Inquiries concerning, and offers to sell the carnotite-type and roscoelite-type ores of the Colorado Plateau area, and the uranium-bearing ores of the Marysvale, Utah district, may be addressed to:

U. S. Atomic Energy Commission
Post Office Box 270
Grand Junction, Colo.

Offers to the Commission to sell any other types of uranium-bearing ores or refined products should be accompanied by a representative 10-pound sample, as well as complete information on the location and character of the material being offered for sale (see Circular No. 1, appendix 3), and should be addressed to:

U. S. Atomic Energy Commission
Post Office Box 30, Ansonia Station
New York 23, N. Y.
Attention: Division of Raw Materials

The S. W. Shattuck Co. of Denver, Colo., is also licensed to purchase certain grades and types of uranium ores.

1. The sample number, if more than one sample is submitted in the same package.
2. The exact location from which the sample was obtained, including the State, county, nearest town, claim name (if any), mine name (if any), and the section, township and range (if known).
3. The estimated amount of material represented by the sample; that is, the length, width, and depth of the deposit insofar as they can be determined.
4. Previous tests made on the sample. For example, if a Geiger counter test was made, include the model number and manufacturer of the instrument, the average background count (in counts per minute) when the sample was tested, and the total count (in counts per minute), including background, registered by the sample when placed a stated distance from the probe. If photographic or analytical tests have been made, include the results.
5. Information on the proportion of the original sample that the submitted sample represents if the submitted sample has been concentrated.
6. Other materials, if any, being mined from the rocks from which the sample was obtained.
7. Other relevant information, including a short description of the deposit.

EXAMINATION OF DEPOSITS

The Geological Survey and Atomic Energy Commission receive many reports that uranium has been discovered, and they also receive many requests to have field representatives examine properties. A representative is sent where strong evidence exists that uranium does occur in sufficient amounts to be of interest to the Commission. Before a prospector requests that a representative be sent to examine a purported uranium deposit, he should submit a representative sample to a laboratory equipped to examine it and to test it for radioactivity.

OFFERING URANIUM FOR SALE

When uranium is found in commercial concentrations, it may be mined and sold either to the U. S. Atomic Energy Commission directly, or to any other person or company within the United States, provided both the buyer and the seller are licensed by the Commission. Detailed instructions on how to sell uranium ores to the Commission, and the prices paid for them, are included in circulars issued by the Commission. (See appendix 3.) Licensing procedures, which are simple to follow, are described in a Commission regulation. (See appendix 4.) It is recommended that prospectors and miners read these circulars and regulations carefully before offering uranium ores for sale.

Refining Company or the United States Atomic Energy Commission (See (a) above). Copper-uranium ores may also be purchased by the Vanadium Corporation of America at Hite, Utah, and the Vitro Chemical Company at Salt Lake City under contractual arrangements with the purchaser.

c. In addition the Vitro Chemical Company may be interested in purchasing unusual uranium-bearing ores which do not readily respond to the treatment processes used in other plants. Inquiries concerning offers of such ores, and samples, should be addressed to the Vitro Chemical Company, 600 West 33d Street South, Salt Lake City 15, Utah.

Carnotite and roscoelite-type ores of the Colorado Plateau will also be purchased, at prices not less favorable than the Commission's prices, at the purchase depots of the following:

Company:	*Location*
Climax Uranium Co	Grand Junction, Colo.
U. S. Vanadium Corp	Rifle, Colo.
U. S. Vanadium Corp	Uravan, Colo.
Vanadium Corp. of America	Durango, Colo.
Vanadium Corp. of America	Naturita, Colo.
[1] Vitro Chemical Co	Salt Lake City, Utah.

[1] Vitro Chemical Company purchases carnotite ores from certain geographical locations only. Offers to sell carnotite ores to this company should be addressed to: Vitro Chemical Co., 600 West 33d Street South, Salt Lake City, Utah.

Marysvale ores will be approximately the same as that contained in Circular 5, Revised, and ores containing as little as 0.10% U_3O_8 will be accepted providing deliveries average approximately 0.15% U_3O_8. The quantity of ore to be purchased and the period over which purchases will be made will be limited by the terms of individual contracts. Correspondence regarding purchase arrangements should be addressed to the American Smelting and Refining Company, P. O. Box 986, Grand Junction, Colorado, or to the United States Atomic Energy Commission, P. O. Box 270, Grand Junction, Colo. Verbal inquiries may be made at either of the above offices or at the Marysvale ore purchase depot.

b. Copper-bearing uranium ores that meet the specifications of Circular 5, Revised, with respect to U_3O_8 content, lime content, physical characteristics and impurities will be purchased at the Commission's Monticello and Marysvale, Utah, ore purchase depots under contractual arrangements with the individual producers. The contracts may provide for payment for some of the copper contained in the ore. Inquiries regarding contractual arrangements for the purchase of these ores should also be addressed to the American Smelting and

In general, the Atomic Energy Commission's domestic uranium program provides for the following:

1. *A guaranteed minimum price effective until April 11, 1958, of $3.50 per pound for uranium oxide (expressed in terms of U_3O_8) contained in domestic ores or mechanical concentrates assaying at least 10 percent U_3O_8.* The price is f. o. b. shipping point, less the cost of refining. This price does not apply to the carnotite-type and roscoelite-type ores of the Colorado Plateau. (See Circular No. 1, appendix 3.)
2. *A guaranteed minimum price effective until April 11, 1958, of $3.50 per pound for uranium oxide (U_3O_8) contained in refined uranium products.* This price is f. o. b. shipping point. (See Circular No. 1, appendix 3.)
3. *A bonus of $10,000, effective until April 11, 1958, for the discovery of a new deposit and the production therefrom of the first 20 short tons of uranium ore or mechanical concentrate assaying 20 percent or more U_3O_8.* This bonus, offered as a special incentive to stimulate prospecting for new high-grade domestic uranium deposits, is paid on delivery of the ore or concentrate to the Commission. It will be paid only once for the production of ore from any single location, but the same

person may receive a bonus for production from each new location that he discovers. The bonus does not apply to the carnotite-type and roscoelite-type ores of the Colorado Plateau area. (See Circular No. 2, appendix 3.)

4. *A bonus, effective through February 28, 1954, for initial production from new and certain existing (domestic) mining properties.* This bonus (see Circular 6, appendix 3) provides for the following:

a. For eligible new mining properties, bonus payments will be made on each pound of uranium oxide in acceptable ore delivered to qualified mills or Commission ore-buying stations up to and including the first 10,000 pounds.

b. For eligible mining properties which have produced less than 10,000 pounds of uranium oxide during the period April 9, 1948, to March 1, 1951, bonus payments will be made on the difference between what the mining property has delivered between April 9, 1948, and March 1, 1951, and 10,000 pounds. (For example, the owner of a mine that has produced 4,000 pounds of uranium oxide between April 9, 1948, and March 1, 1951, may be eligible to receive a bonus on each new pound produced up to and including the next 6,000 pounds.)

c. Bonus payments per pound of uranium oxide in acceptable ores produced from qualified mining properties will range from $1.50 for those ores assaying 0.10% uranium oxide to $3.50 for ores assaying 0.20% or more. Thus the maximum bonus which may be obtained for production from new mines will range from $15,000 to $35,000, depending upon the grade of ore delivered.

5. *Guaranteed minimum prices, effective through March 31, 1958, for the carnotite-type and roscoelite type ores of the Colorado Plateau area.* These provide for payments for a percentage of the vanadium content of ores delivered, as well as payment for the uranium content of the ores. Haulage and development allowances are also paid in addition to the base price (See Circular 5, Revised, appendix 3.)

6. *Provision for a market for other types of ores not acceptable for purchase under terms and conditions of Circular No. 1 or Circular 5, Revised.* These provisions are as follows:

a. Ores of the Marysvale, Utah district, having a minimum content of one-tenth of one percent uranium oxide, will be purchased under contractual arrangements with individual producers. The price schedule for the U_3O_8 content of the

ANSWER: The discovery of uranium on a claim staked before August 1, 1946, will make no change in the locator's rights except that a license is needed to sell or transfer the ore after it has been mined. If uranium is discovered on a claim staked on or after August 1, 1946, the locator will have valuable rights in the uranium deposits but the Government will also keep some rights in the ore. The rights of the locator and the rights of the Government in uranium deposits located after August 1, 1946, are described in Chapter VI, "Laws and Regulations."

QUESTION: *If I find uranium on my property, must I sell it to the Atomic Energy Commission only, or may I sell it to someone else?*

ANSWER: Owners may sell uranium to the Commission or to any private buyer, provided both the buyer and seller are licensed by the Commission. (See ch. VI and appendix 4.)

QUESTION: *If the Atomic Energy Commission is not interested in buying uranium ore that I own, may I offer it to a private company, either for its uranium content or for other minerals that it may contain?*

ANSWER: Yes. However, licensing regulations must be observed. (See ch. VI and appendix 4.)

QUESTION: *Is the Atomic Energy Commission interested in other ores, metals, or minerals that I find or own?*

Schortman's Minerals
6 and 10 McKinley Avenue
Easthampton, Mass.

Ward's Natural Science Establishment
P. O. Box 24, Beechwood Station
Rochester 9, N. Y.

NOTE.—This is not necessarily a complete list of dealers who have samples of uranium minerals for sale. Those listed above have come to the attention of the Atomic Energy Commission or the Geological Survey as dealers who have samples available.

Standard samples, ground to a fine powder and suitable for analytical work or for comparison purposes, are available at:

New Brunswick Laboratory
U. S. Atomic Energy Commission
P. O. Box 150
New Brunswick, N. J.

Samples of the following ores are available:

	Percent U_3O_8
Phosphate rock, No. 1	0.03
Pitchblende, No. 3	3.4
Carnotite, No. 4	0.17
Carnotite, No. 5	0.12

The cost of these analyzed samples is:

$2.50 per 100 g sample.
$5.00 per 200 g sample.

QUESTION: *Will the Government rent or lend me a Geiger counter or other prospecting or mining equipment?*

ANSWER: The Government does not have such equipment available for rental or loan. All equipment necessary or desirable for uranium prospecting, including Geiger counters, is available from commercial dealers.

QUESTION: *What general prospecting methods should I use in looking for uranium?*

ANSWER: General prospecting methods are the same for uranium minerals as for other minerals, except that instruments for detecting radioactivity can also be used. Information on food, clothing, shelter, general equipment, and general methods of prospecting is contained in the publications listed in appendix 1.

QUESTION: *Is it dangerous to prospect for radioactive minerals?*

ANSWER: It is no more dangerous to prospect for radioactive minerals than it is to prospect for other types of minerals. The radioactivity contained in rocks is not dangerous to humans unless such rocks are held in close contact with the skin for very long periods of time.

QUESTION: *I know a place where my watch and compass do not work correctly. Does this mean uranium is present?*

ANSWER: No. Radioactive minerals do not affect the operation of a watch or compass.

QUESTION: *Does the glow that comes from decayed logs or stumps at night mean that uranium is present?*

ANSWER: Phosphorescence, not fluorescence, may cause such a glow, and this does not mean that uranium is present. Fluorescence cannot be observed except under an ultraviolet lamp.

QUESTION: *Do I have to report uranium discoveries to the Atomic Energy Commission?*

ANSWER: No, although such reporting is encouraged. A license from the Commission is needed, however, before uranium that has been mined can be sold or transferred. (See ch. VI and appendix 4.)

QUESTION: *Will the Government buy my land if uranium is found on it, and, if not, will the Government take over the land and mine the uranium for me?*

ANSWER: In accordance with its policy to encourage the development by private enterprise of the uranium resources of the United States, the Atomic Energy Commission follows the practice of buying uranium ores, concentrates, or refined products after they have been mined or processed.

QUESTION: *Do I lose my mineral rights to a claim on which uranium is discovered?*

Bonus payments made under this section will be in addition to any other payments for delivery of the ore. They will be paid directly by the Commission and not by the station or mill.

(e) *Maximum quantity of uranium ores for which bonus payments will be made.* Subject to the conditions of this section, bonus payments will be made on deliveries of uranium ore from an eligible mining property to a station or mill until bonus payments have been made on 10,000 pounds of uranium oxide less the number of pounds, if any, accepted by stations or mills (or any other uranium ore processing plants) from that mining property between April 9, 1948 and February 28, 1951, inclusive.

(f) *Ores for which bonus payments will be made.* Ores for which bonus payments will be made must have been delivered to and paid for by either a station or mill. However, in special cases, bonus payments may be made for ores which have been accepted by the station or mill but for which payment is still pending. Bonus payments will not be made for ores which a station or mill refuses to accept. The weights and final assays made to ascertain the amount of payment due from the station or mill shall be used to determine the amount of bonus payments under this section.

(g) *Which mining properties are eligible.* In order for a mining property to be eligible for bonus payments under this section,

(1) as required by paragraph (e) above, the total quantity of uranium oxide as contained in ore accepted by stations or mills (or any other uranium ore processing plants) from that property between April 9, 1948 and February 28, 1951, inclusive, must have been less than 10,000 pounds; and

(2) the property must be within the United States, its territories, possessions or the Canal Zone; and

ANSWER: No. The Commission is directly interested almost wholly in uranium, although it also appreciates receiving information about thorium deposits. Inquiries concerning other ores, minerals, and metals should be addressed to the U. S. Geological Survey or the U. S. Bureau of Mines, both at Washington 25, D. C.

QUESTION: *Is the Atomic Energy Commission interested in foreign uranium ores?*

ANSWER: The Commission will examine samples of such ores, and consider buying them if, under the regulations of the foreign government concerned, they can be delivered to the Commission. The bonus offers do not apply to foreign ores.

QUESTION: *What are the ways to identify uranium-bearing minerals?*

ANSWER: The methods most useful to prospectors are described in this booklet. In addition, it is possible to apply chemical, optical, and other tests for identification, but most of these methods can only be used in a laboratory.

QUESTION: *What methods are used to mine and concentrate uranium ores?*

ANSWER: In general, the same methods, techniques, and skills used in mining the ore of any metal are necessary for mining uranium. The specific methods used depend upon the type of deposit. When

a commercially valuable deposit is found, the advice of technically qualified specialists is required to determine the best method of mining and concentrating the uranium ore.

QUESTION: *May I take or ship a Geiger counter out of the United States to another country to prospect for uranium?*

ANSWER: An Atomic Energy Commission license to export a Geiger counter must be obtained prior to taking or shipping a counter out of the United States.

duction of uranium-bearing ores. It is intended to encourage and assist the development of new sources of domestic uranium production in the interest of the common defense and security.

(b) *Production bonus established.* The U. S. Atomic Energy Commission will pay a bonus under the conditions set forth in this section for delivery to a Commission ore-buying station or a qualified uranium mill (hereafter called station or mill) of uranium ores from an eligible mining property up to the maximum quantities specified in this section.

(c) *Term of this section.* This section will apply to deliveries made under its terms between March 1, 1951, and February 28, 1954, inclusive.

(d) *Payment of the bonus.* Bonus payments will be computed on the following basis:

Ores assaying less than 0.10% U_3O_8: no payment.

Ores assaying 0.10% U_3O_8 and more, as follows:

U_3O_8 Assay:	*Payment per pound U_3O_8*
0.10 percent	$1.50
0.11 percent	1.70
0.12 percent	1.90
0.13 percent	2.10
0.14 percent	2.30
0.15 percent	2.50
0.16 percent	2.70
0.17 percent	2.90
0.18 percent	3.10
0.19 percent	3.30
0.20 percent and more	3.50

Fractional parts of a pound will be paid for on a pro rata basis to the nearest cent. Assays will be adjusted to the nearest 0.01% for purposes of payment. Weights are avoirdupois dry weights.

(b) *Quality and size.* Ores will not be accepted by buyer under §§ 60.5 and 60.5a which, in buyer's judgment:

(1) Contain less than 0.10 percent U_3O_8;

(2) Contain more than three parts of lime ($CaCO_3$) to one part of V_2O_5, or a total of more than 6 percent lime in the ore;

(3) Contain impurities deleterious to buyer's extraction process or for any other reason are not amenable to it;

(4) Contain lumps in excess of twelve inches in size.

NOTE.—The Commission will be interested in discussing arrangements for delivery to it of types of uranium-bearing materials other than those for which guaranteed prices have been established, such as tailings, mill products, and ores of types not acceptable under §§ 60.5 and 60.5a.

(60 Stat. 755–775; 42 U. S. C. 1801–1819. Interpret or apply sec. 5, 60 Stat. 761, 42 U. S. C. 1805)

Effective March 1, 1951 through March 31, 1958.

Dated at Washington, D. C., this 26th day of February 1951.

By order of the Commission.

M. W. BOYER,
General Manager.

[F. R. Doc. 51-3190; Filed Mar. 12, 1951; 8:45 a. m.]

ATOMIC ENERGY COMMISSION

[10 CFR, Part 60]

Part 60—Domestic Uranium Program

[Domestic Uranium Program Circular 6]

BONUS FOR INITIAL PRODUCTION OF URANIUM ORES FROM DOMESTIC MINES

Sec. 60.6 *Bonus for initial production of uranium ores from new domestic mines*—(a) *What this section does.* This section provides for bonus payments for initial and certain other pro-

GLOSSARY

Before attempting to prospect for uranium, it is desirable that the reader have an understanding of some of the special terms used in the mining and geological professions. Following are a few of the terms that are used in this booklet, and with which prospectors should become familiar. More detailed definitions of specialized terms can be found in the books listed in Appendix 1.

CRYSTAL: A solid bounded by smooth, flat surfaces which are an outward expression of a definite internal structure.

ELEMENT: Any of the basic kinds of matter from which all substances on earth are formed. The metal uranium is an element.

MINERAL: An inorganic substance, composed of an element or a group of elements, occurring in nature. Gold is an example of a mineral which contains only one element. Quartz, composed of silicon and oxygen, is an example of a mineral which contains two elements. Many minerals contain three or more elements.

ORE: A mineral or rock that can be profitably mined and sold. It is incorrect to describe a mineral or rock as an ore unless it has commercial value.

OUTCROP: That part of an ore body or rock formation which appears at the surface of the ground.

OVERBURDEN: Earth or nonvaluable rock occurring between an ore deposit and the surface of the ground.

RADIOACTIVITY: The property of certain elements, including uranium, to emit invisible rays that can be detected only with special instruments such as the Geiger counter.

ROCK: Solid matter, composed of one or more minerals, occurring in nature.

SPECIFIC GRAVITY: The weight of a substance compared with the weight of an equal volume of water. Pitchblende, for example, is said to have a specific gravity of approximately nine because it is approximately nine times as heavy as an equal volume of water.

URANIUM OXIDE: A chemical compound, composed of uranium and oxygen. Since the end product of most chemical analyses of uranium ores is the uranium oxide U_3O_8 (three atoms of uranium to eight atoms of oxygen) the uranium content of ores is frequently expressed in terms of this chemical compound.

VEIN: A mineral deposit filling a crack or fissure in rock, thus forming a well-defined mineralized zone. When an ore deposit consists of one or more veins that can be mined as a whole, it is frequently called a "lode."

one will be paid for. Any such announcement will be made by posting a notice to this effect at the Monticello depot and through such other channels as are deemed suitable to achieve maximum dissemination among producers. Excess V_2O_5 shall be deemed to be buyer's property.

(3) *Allowances.* (i) A development allowance of $0.50 per pound U_3O_8 contained in ores assaying 0.10 percent U_3O_8 or more in recognition of the expenditures necessary for maintaining and increasing developed reserves of uranium ores. Fractional parts of a pound will be paid for on a pro rata basis to the nearest cent. Sellers accepting this allowance are deemed to agree to spend such funds for the development or exploration of their properties. Sellers delivering less than 1,000 short tons per calendar year will not be required to submit an accounting record of expenditures for development or exploration pursuant to this agreement but sellers delivering in excess of 1,000 short tons per calendar year will be required, under the terms of their contracts, to submit proof satisfactory to the Commission that funds equivalent to the amount received as development allowance have been spent for development or exploration either during the contract period or within six months thereafter, unless otherwise provided in the contract.

(ii) A haulage allowance of 6¢ per ton mile for transportation of ore paid for under §§ 60.5 and 60.5a from the mine where produced to the purchase depot specified by the Commission, up to a maximum of 100 miles. The haulage distance from the mine to the purchase depot will be determined by the Commission and its decision will be final. Tonnages for purposes of this allowance shall be calculated on the basis of natural weights rather than dry weights.

(4) *Adjustment of assays.* Assays shall be adjusted to the nearest 0.01 percent for purposes of payment.

of his ore, it is suggested that before shipment and delivery to the purchase depot a representative sample be submitted to the buyer or to one of the umpires for assay at seller's expense. The buyer at its discretion may assay a limited number of samples without charge.

(ii) Ores assaying 0.10 percent U_3O_8 and more, as follows:

U_3O_8 assay:	*Payment per pound U_3O_8*
0.10 percent	$1.50
0.11 percent	1.70
0.12 percent	1.90
0.13 percent	2.10
0.14 percent	2.30
0.15 percent	2.50
0.16 percent	2.70
0.17 percent	2.90
0.18 percent	3.10
0.19 percent	3.30
0.20 percent and more	3.50

(iii) Premiums on uranium: $0.75 per pound for each pound of U_3O_8 in excess of 4 pounds U_3O_8 per short ton (2,000 pounds per ton) of ore and an additional premium of $0.25 per pound for each pound in excess of ten pounds U_3O_8 per short ton. Fractional parts of a pound will be paid for on a pro rata basis to the nearest cent.

(2) *Vanadium.* V_2O_5 at $0.31 per pound up to, but not exceeding, ten pounds of V_2O_5 for each pound of U_3O_8 contained in ores. No factor will be included for V_2O_5 in excess of ten pounds for each pound of U_3O_8, although buyer may, from time to time, publicly announce that, for limited periods by written agreements with individual producers, V_2O_5 in excess of ten-to-

APPENDIX 1

SOURCES OF ADDITIONAL INFORMATION

Selected Practical Publications Concerning Uranium Minerals and Prospecting

These publications may be obtained from the firms or agencies which publish them. Several are also available in libraries and book stores.

YOU CAN FIND URANIUM, by Joseph L. Weiss and William R. Orlandi ---------- $2.00

Published 1949 by J. B. Weiland & Co., Box 2189, San Francisco 26, Calif. A nontechnical guide including information on the identification of uranium minerals, prospecting for uranium minerals and where to look for them, how to stake a claim, and how to proceed after discovery. (128 pages)

HANDBOOK OF URANIUM MINERALS; A PRACTICAL GUIDE FOR URANIUM PROSPECTING, by Jack DeMent and H. C. Dake -- $2.00

Second edition published 1948 by the Mineralogist Publishing Co., 329 Southeast 32d Avenue, Portland 15, Oreg. This booklet gives a description of the geographical areas in which radioactive minerals have been found in the past, a catalog of radioactive minerals, prospecting methods, and other information. (96 pages)

PROSPECTORS' GUIDE FOR URANIUM AND THORIUM MINERALS IN CANADA ---------- No charge

Published 1948 by the Mines, Forests and Scientific Services Branch, Bureau of Mines, Department of Mines and Resources, Ottawa, Canada. This booklet describes uranium and thorium

minerals with special reference to prospecting in Canada. (37 pages)

THE ROCK BOOK, by Carrol Lane Fenton and Mildred Adams Fenton ---------- $6.00

Published 1940 by Doubleday & Co., 14 West 49th Street, New York 20, N. Y. This is a discussion of geology, rocks, and minerals in general, for persons who have no previous knowledge of these subjects and wish to become familiar with them. Includes illustrations and a list of books for further reading and study. (359 pages)

RADIOACTIVE URANIUM AND THORIUM, compiled by John W. Anthony---------- 25 cents

Bulletin No. 13, Arizona Bureau of Mines, University of Arizona, Tucson, Ariz. Besides a brief discussion of the occurrence, relative abundance, and physical characteristics of uranium and thorium minerals, this publication includes identification tables and a section on detection of radioactivity. Free to residents of Arizona. (Mimeographed, 22 pages)

HANDBOOK FOR PROSPECTORS AND OPERATORS OF SMALL MINES, by M. W. von Bernewitz, revised by Harry C. Chellson----- $4.50

Fourth edition published 1943 by McGraw-Hill Book Co., Inc., 330 West 42d Street, New York 18, N. Y. The section dealing with radioactive ores is short, but the book contains useful information on prospecting in general. (372 pages)

RADIATION INSTRUMENT CATALOG NO. 2 (Part 1 & 2) (1950). $2.00

The U. S. Atomic Energy Commission publishes this catalog describing different types of radiation detection instruments and accessories. This catalog may be obtained from the Office of Technical Services, Department of Commerce, Washington 25, D. C.

sampling. Moisture determinations, analyses and settlement sheets, together with the check in payment, will be mailed to seller.

(i) *Inquiries.* All inquiries concerning the provisions of this section and § 60.5a, offers to deliver ores, or questions about the Commission's domestic uranium program in the Colorado Plateau area should be addressed to:

United States Atomic Energy Commission, Post Office Box 270, Grand Junction, Colorado; Telephone: Grand Junction 3000.

(j) *Licenses.* Arrangements will be made by the Commission for the issuance of licenses, pursuant to the Atomic Energy Act of 1946, covering deliveries of source material to the Commission under this section and § 60.5a.

(k) *Limitation of commitment.* Commitments by the Commission to accept delivery of ores are limited to the provisions of this section and § 60.5a as amended from time to time, or to written contracts between the Commission and sellers. Other commitments purporting to be made by the Commission's field personnel or other agents of the Commission will not bind the Commission unless they are in accord with the provisions of this section and § 60.5a or other official circulars.

§ 60.5a *Schedule I; minimum prices, specifications, and conditions*—(a) *Prices.* Payment for delivery of the ores will be computed on the following basis:

(1) *Uranium.* (i) Ores assaying less than 0.10 percent: no payment. Any such ores which are delivered to the purchase depot shall, unless otherwise specifically agreed to by buyer, become the property of the buyer as liquidated damages for buyer's expense of weighing, sampling, and assaying, and after sampling may be placed in process, commingled, or otherwise disposed of by buyer. If seller has any question as to the quality

of the purchase depot and such weight will be accepted as final. A weight ticket will be furnished seller or his representative for each load. Each lot of ores will be sampled promptly by the buyer according to standard practice and such sampling will be accepted as final. Seller or his representative may be present at the sampling at his own expense. The absence of seller or his representative shall be deemed a waiver of this right. Buyer will make moisture determinations according to standard practices in ore sampling. All final samples will be divided into four pulps and distributed as follows: (1) The seller, or his representative, will receive one pulp; (2) the buyer will retain one pulp; (3) the other two pulps will be reserved for possible umpire analysis. The buyer's pulp will be assayed by the buyer. The seller may, if he desires, and at his own expense, have his pulp assayed by an independent assayer. In case of disagreement on assays as to any constituent of the ores, an umpire shall be selected in rotation from a list of umpires approved by the buyer whose assays shall be final if within the limits of the assays of the two parties; if not, the assay which is nearer to that of the umpire shall prevail. The party whose assay is the farther from that of the umpire shall pay the cost of the umpire's assay for the constituent of the ores which is in dispute. In the event that the umpire's assay is equally distant from the assay of each party, costs will be split equally. In case of seller's failure to make or submit assays, buyer's assays shall govern. After sampling, the ores may be placed in process, commingled, or otherwise disposed of by buyer.

(h) *Payment.* Buyer will make payment promptly but payment will not be made until an entire minimum lot of ten short tons (2,000 pounds per ton) has been delivered and accepted, unless special arrangements have been agreed upon by buyer, in which case there may be an extra charge for assaying and

MANUAL OF ANALYTICAL METHODS FOR THE DETERMINATION OF URANIUM AND THORIUM IN THEIR ORES, prepared by the New Brunswick Laboratory, Atomic Energy Commission-- 20 cents

This manual is a compilation of chemical methods for the analysis of pitchblende, carnotite-bearing sandstone, shales, phosphate rock, and monazite sands. For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

MINERALOGY OF URANIUM AND THORIUM BEARING MINERALS, by D'Arcy George---------- 60 cents

Published by the Technical Information Service, Oak Ridge, Tennessee. This book may be obtained by writing to the Office of Technical Services, Department of Commerce, Washington, D. C. This book describes the distribution, chemistry, tests, mode of occurrence and classification of the uranium and thorium bearing minerals.

A GLOSSARY OF URANIUM- AND THORIUM-BEARING MINERALS, by Judith W. Frondel and Michael Fleischer--------- No charge

This booklet may be obtained by writing to the Director, Geological Survey, Washington, D. C. It lists chemical, optical, and X-ray diffraction data on uranium- and thorium-bearing minerals.

A GUIDE TO URANIUM PROSPECTORS IN MICHIGAN, by B. E. Kennedy---------- 50 cents

Published 1949 by Michigan Department of Conservation, Geological Survey Division, Lansing 13, Michigan. Contains section dealing with the state laws that apply to prospecting and mining on private and public lands in Michigan. Free to the residents of Michigan. 16 pages.

RADIOACTIVE ORES THE PROSPECTOR SHOULD KNOW, by David J. White---------- 20 cents

GMI Short Paper No. 18, published 1949 by the Department of Geology and Mineral Industries, State of Oregon, 702 Woodlark Building, Portland 5, Oreg. Includes map of Oregon showing principal mountain ranges where mineral veins occur; also bibliography. 16 pages.

NOTES FOR URANIUM PROSPECTORS..... No charge

Issued by Washington State Division of Mines and Geology, Room 404, Transportation Building, Olympia, Washington. 5 pages.

HANDBOOK OF CHEMICAL METHODS FOR THE DETERMINATION OF URANIUM IN MINERALS AND ORES..... 1 shilling

Issued by the Chemical Research Laboratory, Department of Scientific and Industrial Research. Published by His Majesty's Stationary Office, P. O. Box 569, London S. E. 1. 22 pages.

Magazine Articles

CONSTRUCTION OF GEIGER COUNTERS

Popular Mechanics, February 1949, "How to build a Geiger-Mueller Uranium Survey Meter," by F. L. Brittin.

Radio-Electronics, July 1949, "Prospecting for Uranium Ore Using G–M Counters," by S. M. Freedman.

Radio News, July 1949, "Build Your Own Geiger Counter," by Walter B. Ford.

THE SCINTILLATION COUNTER

Economic Geology, March 1950, "Radiation Surveys with a Scintillation Counter," by George M. Brownell.

NYO 1523, "An Alpha Scintillation Counter for Laboratory Measurement," by Robert T. Graveson, Hugo DiGiovanni, and Harris D. LeVine. Available at the Office of Technical Services, Department of Commerce, Washington, D. C., price $0.15.

unexpired terms of §§ 60.3 and 60.3a (through April 11, 1951). It is believed, however, that in most cases the provisions of this section and § 60.5a will be more favorable to producers.

(c) *Definitions.* As used in this section and in § 60.5a, the term "buyer" refers to the U. S. Atomic Energy Commission, or its authorized purchasing agent. The term "ore" does not include mill tailings or other mill products. The term "seller" refers to any person offering uranium ores for delivery to the Commission. Weights are avoirdupois dry weights, unless otherwise specifically provided.

(d) *Deliveries of not to exceed 1,000 tons per year.* To aid small producers, any one seller may deliver without a written contract but otherwise in accordance with this circular up to, but not exceeding, 1,000 short tons (2,000 pounds per ton) of ores during any calendar year.

(e) *Deliveries in excess of 1,000 tons per year.* Sellers desiring to deliver in excess of 1,000 short tons (2,000 pounds per ton) of ores during any calendar year will be required to enter into a contract with the Commission providing for, among other things, a rate of delivery and the total quantity of ore to be delivered.

(f) *Delivery.* Seller, at his own expense, shall deliver and unload all ores at the buyer's depot at Monticello, Utah. Deliveries shall be in lots of not less than 10 short tons (2,000 pounds per ton) unless special arrangements have been agreed upon by buyer, but such lots may be delivered in more than one load. Days and hours during which ore may be delivered will be posted at the depot.

(g) *Weighing, sampling and assaying.* Buyer will bear the cost of weighing, sampling, and assaying. The net weight of each load will be determined by the buyer's weighmaster on scales which will be provided by the buyer at or in the vicinity

TITLE 10—ATOMIC ENERGY

Chapter I—Atomic Energy Commission

[Domestic Uranium Program Circular 5, Revised]

PART 60—DOMESTIC URANIUM PROGRAM

GUARANTEED MINIMUM PRICE FOR URANIUM-BEARING CARNOTITE-TYPE OR ROSCOELITE-TYPE ORES OF COLORADO PLATEAU AREA

Section 60.5 and § 60.5a of Title 10, Code of Federal Regulations, are amended by increasing the prices and premiums to be paid after March 1, 1951, for uranium ores, so that § 60.5 and § 60.5a, as amended, shall read as follows:

§ 60.5 *Guaranteed minimum price for uranium-bearing carnotite-type or roscoelite-type ores of the Colorado Plateau area*—(a) *Guarantee.* To stimulate domestic production of uranium-bearing ores of the Colorado Plateau area, commonly known as carnotite-type or roscoelite-type ores, and in the interest of the common defense and security, the United States Atomic Energy Commission hereby establishes the guaranteed minimum prices specified in § 60.5a effective during the period, March 1, 1951, through March 31, 1958, for the delivery of such ores to the Commission at Monticello, Utah, in accordance with the terms of this section and § 60.5a.

NOTE.—In §§ 60.1 and 60.2 (Domestic Uranium Program, Circulars No. 1 and 2), the Commission established guaranteed prices for other domestic uranium-bearing ores, mechanical concentrates, and refined uranium products.

(b) *Effect on §§ 60.3 and 60.3a.* Sections 60.3 and 60.3a, which also apply to carnotite and roscoelite ores, are not revoked by the issuance of this section and § 60.5a and sellers may elect to deliver ore under the provisions of §§ 60.3 and 60.3a rather than under this section and 60.5a, at their option, during the

A TEXTBOOK OF MINERALOGY, by Edward Salisbury Dana-- $6.00

Fourth edition published 1932 by John Wiley & Sons, Inc., 440 4th Avenue, New York 16, N. Y. This book presents specialized, detailed and technical information concerning most of the common minerals. (851 pages).

PUBLICATIONS OF THE GEOLOGICAL SURVEY, MAY 1948 AND SUPPLEMENTS THERETO---------- No charge

Published by the U. S. Geological Survey. This booklet, which contains a list of the geological and mining publications distributed by the Survey, may be obtained by writing to the Director, U. S. Geological Survey, Washington 25, D. C.

Maps

GEOLOGIC AND MINERAL MAPS: These may be obtained from the U. S. Geological Survey. A list of the maps available is included in the booklet, PUBLICATIONS OF THE GEOLOGICAL SURVEY, MAY, 1948, referred to above. These geologic and mineral maps are useful to the prospector only in a general way, since they do not refer specifically to radioactive minerals.

TOPOGRAPHIC MAPS: Index Map Circulars for individual States may be obtained without charge from the U. S. Geological Survey, Washington 25, D. C. Topographic maps published to date cover only about one-half of the country. The Index Map Circulars describe for which parts of each State detailed maps are available. These maps are also useful to the uranium prospector only in a general way.

Libraries

The following libraries have been designated by Congress to receive prints, as issued, of all publications, including those having to do with mining and prospecting, which are printed by the Government for public distribution.

LIST OF LIBRARIES

State	City	Library
Alabama	Birmingham	Public.
	Montgomery	Department of Archives and History.
	University	University of Alabama.
Arizona	Phoenix	Department of Library and Archives.
	Tucson	University of Arizona.
Arkansas	Fayetteville	University of Arkansas.
California	Berkeley	University of California.
	Claremont	Pomona College.
	Eureka	Free.
	Fresno	County Free.
	Los Angeles	Public.
	Sacramento	California State.
	San Francisco	Public.
	Stanford University.	Stanford University.
Colorado	Boulder	University of Colorado.
	Fort Collins	Colorado State College.
Connecticut	Hartford	Connecticut State.
		Trinity College.
	Middletown	Wesleyan University.
	New Haven	Yale University.
	Storrs	University of Connecticut.
Delaware	Wilmington	Wilmington Institute Free.
Florida	Coral Gables	University of Miami.
	Gainesville	University of Florida.
Idaho	Moscow	University of Idaho.
	Pocatello	University of Idaho, Southern Branch.
Illinois	Chicago	John Crerar.
		Public Document Department.
		University of Chicago.
	Evanston	Northwestern University.
	Springfield	Illinois State, General Library Division.
	Urbana	University of Illinois.

of the weights and assays of material produced will be undertaken by the Commission. On the basis of a report of such inspection and verification, if favorable, the Commission will determine the quantity of ore produced. If this determination indicates that the production requirements established in paragraph (a) of this section have been met, the Commission will pay the bonus in addition to the price established under § 60.1, when delivery of such ore is completed.

(f) *Inquiries and communications.* Inquiries about this section and all other communications should be addressed as follows:

U. S. Atomic Energy Commission
P. O. Box 30, Ansonia Station
New York 23, N. Y.
Attention: Division of Raw Materials.

(g) *Licenses.* Arrangements will be made by the Commission for the issuance of licenses, pursuant to the Atomic Energy Act of 1946, covering deliveries of source material to the Commission under this section. (Sec. 5 (b), 60 Stat. 761)

Effective date. This circular will become effective at midnight, April 11, 1948.

Dated at Washington, D. C., this 9th day of April 1948.

By order of the Commission.

WALTER J. WILLIAMS,
Acting General Manager.

for any other reason a bonus is not payable. In making this determination the Commission will be guided by the mining laws of the United States which provide, generally, that lode locations may extend in lode or vein formation up to 1,500 feet along the vein and in width 300 feet on each side of the middle of the vein, the end lines of the location being parallel to each other; and that placer locations may not be greater than 20 acres for each location or 160 acres in a single location for up to eight locators. The fact that a bonus has already been received will not prevent the payment of another bonus to the same person with respect to production from a different location.

(d) *Notice of discovery and production.* Notice of the discovery of a uranium deposit and production therefrom believed to meet the requirements of paragraph (a) of this section should be forwarded to the Commission by letter or telegram, to the address specified in paragraph (f) of this section, together with an offer to deliver such ore to the Commission under § 60.1. In addition to the information and the 10-pound sample required under § 60.1, the following must be furnished:

(1) A brief description of the location of property indicating its size and relationship to mineral monuments or the public land surveys;

(2) Name of owner of record of property;

(3) Location of Recorder's Office where ownership is recorded.

NOTE: The reporting requirements hereof have been approved by the Bureau of the Budget pursuant to the Federal Reports Act of 1942.

(e) *Inspection of claim.* Upon receipt of a notice of discovery and sample, forwarded as required in § 60.1, an anlysis of the sample will be made. If the sample and supporting data indicate the claim is likely to meet the requirements of paragraph (a) of this section, an inspection of the property and verification

State	City	Library
Indiana	Bloomington	Indiana University.
	Fort Wayne	Public.
	Indianapolis	Indiana State.
Iowa	Grinnell	Grinnell College.
	Iowa City	State University of Iowa.
Kansas	Lawrence	University of Kansas.
Kentucky	Lexington	University of Kentucky.
	Louisville	Free Public.
Louisiana	Baton Rouge	Louisiana State University.
	New Orleans	Howard-Tilton Memorial.
Maine	Orono	University of Maine.
Maryland	Baltimore	Enoch Pratt Free. Johns Hopkins University.
Massachusetts	Boston	Public. State.
	Cambridge	Harvard University, Document Division.
	Wellesley	Wellesley College.
	Worcester	Free Public.
Michigan	Ann Arbor	University of Michigan.
	Detroit	Public.
Minnesota	Minneapolis	University of Minnesota.
	St. Paul	Minnesota State. Public.
Mississippi	University	University of Mississippi.
Missouri	Columbia	University of Missouri.
	Kansas City	Public.
	St. Louis	Do.
Montana	Helena	Do.
Nebraska	Omaha	Municipal University of Omaha.
Nevada	Carson City	Nevada State.
New Jersey	New Brunswick	Rutgers University.
	Trenton	New Jersey State.
New Mexico	Albuquerque	University of New Mexico.
	Santa Fe	New Mexico State Law.
New York	Albany	New York State.
	Brooklyn	Public, Montague Branch.
	Ithaca	Cornell University.

State	City	Library
New York—Con.	New York	College of the City of New York.
		Columbia University.
		Astor Branch.
		Lenox Branch.
	Schenectady	Union College.
North Carolina	Chapel Hill	University of North Carolina.
	Durham	Duke University.
	Greensboro	Agricultural and Technical College.
	Raleigh	North Carolina State College.
Ohio	Bowling Green	Bowling Green State University.
	Cincinnati	Public.
	Cleveland	Adelbert College.
		Public.
	Columbus	Ohio State.
		Ohio State University.
	Dayton	Public.
	Oberlin	Oberlin College.
	Oxford	Miami University.
	Toledo	Public.
Oklahoma	Durant	Southeastern Teachers' College.
	Norman	University of Oklahoma.
	Oklahoma City	Oklahoma State.
	Stillwater	Agricultural and Mechanical College.
Oregon	Portland	Library Association.
	Salem	Oregon State.
Pennsylvania	Allentown	Muhlenberg College.
	Harrisburg	Pennsylvania State.
	Philadelphia	Free.
	Pittsburgh	Carnegie, Order Department.
	Reading	Public.
	State College	Pennsylvania State College.
Philippine Islands	Manila	University of Philippines.
Rhode Island	Providence	Rhode Island State.
South Carolina	Clemson	Clemson College.
South Dakota	Brookings	Lincoln Memorial, South Dakota State.
	Vermillion	University of South Dakota.

worked for uranium (or in the case of production from lands not covered by such a mining location, from an area comparable thereto, as determined by the Commission). This bonus offer does not apply to delivery of ores of the Colorado Plateau area commonly known as carnotite-type or roscoelite-type ores; under § 60.3, the Commission has established guaranteed minimum prices for delivery of such ores including a development allowance and premiums for better grade.

NOTE: The term "domestic" in this section, referring to uranium-bearing ores and mechanical concentrates, means such uranium, ores and concentrates produced from deposits within the United States, its territories, possessions and the Canal Zone.

(b) *Nature of bonus.* The bonus of $10,000 offered in this section is a bonus to encourage the discovery of new uranium resources. However, it will be paid, not for discovery alone, but only in connection with delivery to the Commission, pursuant to § 60.1, of ores produced from the location, as an independent and additional part of the price established by the Commission under that section.

(c) *Who may claim.* The person lawfully entitled to deliver ore to the Commission pursuant to § 60.1, may claim the bonus offered in paragraph (a) of this section. A bonus will be paid only once for production of ores from any single lode or placer location (or, in the case of production from lands not covered by such a location, from an area comparable thereto, as determined by the Commission). The Commission expressly reserves the right to determine whether production from a given location is the first production from such location for the purposes of this section or whether such location or property has previously been worked for uranium, whether production is such as to which a bonus has already been paid, or whether

(g) *Other valuable minerals.* In making payment for material delivered to it in accordance with this section, the Commission will give consideration to the existence of recoverable gold, silver, radium, thorium, or any other valuable constituent in the light of the cost of recovery.

(h) *Licenses.* Arrangements will be made by the Commission for the issuance of licenses, pursuant to the Atomic Energy Act of 1946, covering deliveries of source material to the Commission under this section. (Sec. 5 (b), 60 Stat. 761)

Effective date. This circular will become effective at midnight, April 11, 1948.

Dated at Washington, D. C., this 9th day of April 1948.

By order of the Commission.

WALTER J. WILLIAMS,
Acting General Manager.

Circular No. 2

BONUS FOR THE DISCOVERY AND PRODUCTION OF HIGH-GRADE DOMESTIC URANIUM ORE

§ 60.2 *Bonus for the discovery and production of high-grade domestic uranium ore*—(a) *Discovery and production bonus.* To stimulate prospecting for, discovery of, and production from new high-grade domestic uranium deposits and in the interest of the common defense and security the United States Atomic Energy Commission will pay, in addition to the guaranteed minimum price established in § 60.1, a bonus of $10,000 for delivery to the Commission, after the effective date of this section, of the first 20 short tons (2,000 pounds avoirdupois dry weight per ton) of uranium-bearing ores or mechanical concentrates assaying 20 percent or more U_3O_8 by weight from any single mining location, lode or placer, which has not previously been

State	City	Library
Tennessee	Knoxville	University of Tennessee.
	Nashville	Joint University.
Texas	Austin	Texas State.
	Canyon	West Texas State Teachers' College.
	Dallas	Public.
	Fort Worth	Do.
	Galveston	Rosenberg.
	Houston	Public.
	Lubbock	Texas Technological College.
	San Antonio	Carnegie.
Utah	Provo	Brigham Young University.
Virginia	Richmond	Virginia State.
	University	University of Virginia.
Washington	Olympia	Washington State.
	Pullman	State College.
	Seattle	Public.
		University of Washington.
West Virginia	Morgantown	West Virginia University.
Wisconsin	Milwaukee	Law Library of Milwaukee.
		Public.
Wyoming	Laramie	University of Wyoming.

APPENDIX 2

MANUFACTURERS AND DISTRIBUTORS OF PORTABLE GEIGER COUNTERS SUITABLE FOR PROSPECTING

Prices range generally from about $100 to $300, although some manufacturers are now developing counters that will sell for less. For specifications, exact prices and details of equipment, prospectors should consult manufacturers' catalogs. Some manufacturers will tropicalize their instruments upon request, with or without a fee. Some companies also furnish instructions for using their instruments, and some sell unassembled parts and home construction plans.

Antsell Instrument Co.
6515 Anstell Street
Detroit 13, Mich.

Atomic Research Corp.
T–380 Peterson Field
Colorado Springs, Colo.

V. G. Baker
Fairbanks, Alaska

Berkeley Scientific Co.
Sixth and Nevin Avenue
Richmond, Calif.

Cosmic Counters
112 Cornell Avenue
Swarthmore, Pa.

Detectron Co.
5637 Cahuenga Boulevard
North Hollywood, Calif.

El-Tronics, Inc.
2647 North Howard Street
Philadelphia 33, Pa.

Engineers Syndicate, Ltd.
5176 Hollywood Boulevard
Hollywood 27, Calif.

Fisher Research Laboratory, Inc.
1961–65 University Avenue
Palo Alto, Calif.

(d) *Purchase contract.* Upon receipt of an offer and sample, an analysis of the sample will be made. If the sample and the information furnished are determined by the Commission to meet the conditions of this section, the Commission will forward to the person making the offer a form of contract containing applicable terms and conditions ready for his acceptance. Prices will be not less than the applicable prices of paragraph (b) of this section.

(e) *Minimum quantity and grade.* No delivery will be accepted under this section of less than ten short tons (2,000 pounds per ton) of ores or mechanical concentrates, nor of ore or mechanical concentrates which assay less than 10 percent U_3O_8 by weight. No delivery will be accepted under this section of less than one short ton of refined uranium, nor of refined uranium which contains by weight less than 97 percent U_3O_8 in black uranium oxide or 87 percent U_3O_8 in sodium uranate. However, the Commission will be interested in negotiating reasonable terms with respect to deliveries of high-grade ores and refined products in lesser quantities and grades than those specified in this section.

(f) *Large quantities or special conditions.* The prices established in paragraph (b) of this section are minimum prices. The Commission may by negotiations establish higher prices for guaranteed delivery of lots of ores or mechanical concentrates substantially in excess of ten short tons, or for lots of refined uranium substantially in excess of one short ton. The Commission also may by negotiation establish higher prices for delivery of ores, mechanical concentrates, or refined uranium under other special conditions, taking into consideration such factors as refining and milling costs, transportation costs, and other applicable factors.

the Commission's operations, to be determined by the Commission after assay of a representative sample.

(2) For refined uranium products, $3.50 per pound contained U_3O_8 (uranium oxide).

Prices are f. o. b. railroad cars or trucks at shipping point designated by the Commission convenient to mine, mill, or refinery. Weights are avoirdupois dry weight.

(c) *Making an offer.* Anyone who has domestic refined uranium, high-grade uranium-bearing ores, or mechanical concentrates of the quantity and grade specified in paragraph (e) of this section, may offer it for delivery to the Commission by sending a letter or telegram addressed as follows:

U. S. Atomic Energy Commission
P. O. Box 30, Ansonia Station
New York 23, N. Y.
Attention: Division of Raw Materials.

With each offer there should be furnished a representative ten-pound sample and the following information:

(1) Location of property;

(2) Character of material offered for delivery (state whether refined uranium, mechanical concentrates, or uranium-bearing ores, indicating approximate composition);

(3) Amount of material offered;

(4) Location of material offered;

(5) Origin of material if offered by other than producer;

(6) If material is owned, in whole or in part, by any person other than the person making the offer, the name of each person having such ownership and nature of his rights; and

(7) Name and address of person making the offer.

NOTE: The reporting requirements hereof have been approved by the Bureau of the Budget pursuant to the Federal Reports Act of 1942.

Forty-Niner Corp.
5245 Grand River Avenue
Detroit 8, Mich.

Geophysical Instrument Co.
1820 North Nash Street
Arlington, Va.

Geophysical Measurements Corp.
802–805 Wright Building
Tulsa 3, Okla.

Halross Instruments Corp., Ltd.
171 Garry Street
Winnipeg, Manitoba, Canada

Herbach & Rademan, Inc.
522 Market Street
Philadelphia 6, Pa.

Kelly-Koett Manufacturing Co.
12 East Sixth Street
Covington, Ky.

Menlo Research Laboratory
P. O. Box 522
Menlo Park, California

National Technical Laboratories
820 South Mission Street
South Pasadena, Calif.

The Newman-Stern Co.
Newman-Stern Building
East 12th Street
Cleveland 14, Ohio

Nuclear Instrument & Chemical Corp.
223–233 West Erie Street
Chicago 10, Ill.

Omaha Scientific Supply Corp.
3623 Lake Street
(Mail Address, Box 1706)
Omaha 4, Nebr.

Precision Radiation Instruments, Inc.
1101 North Paulina Street
Chicago 22, Ill.

The Radiac Co.
489 Fifth Avenue
New York 17, N. Y.

Radiation Counter Laboratories
1844 West Twenty-first Street
Chicago 8, Ill.

Radio Specialists Co.
417 West 12th Avenue
Denver 4, Colo.

Service Diamond Tool Co.
Radioactivity Instrument Division
2505 Burdette Avenue
Ferndale 20, Mich.

Tracerlab, Inc.
130 High Street
Boston 10, Mass.

Special Instruments Laboratory, Inc.
1003 Highland Avenue
Knoxville, Tenn.

Victoreen Instrument Co.
5806 Hough Avenue
Cleveland 3, Ohio

Technical Associates
3730 San Fernando Road
Glendale 4, Calif.

Western Radiation Laboratory
1107 West 24th Street
Los Angeles 7, Calif.

(NOTE.—This list includes firms which had come to the attention of the Geological Survey or the Atomic Energy Commission by the publication date of this booklet. It is not necessarily complete.)

APPENDIX 3

UNITED STATES ATOMIC ENERGY COMMISSION DOMESTIC PRICE SCHEDULES

Circular No. 1

TEN YEAR GUARANTEED MINIMUM PRICE

§ 60.1 *Ten year guaranteed minimum price*—(a) *Guarantee.* To stimulate domestic production of uranium and in the interest of the common defense and security the United States Atomic Energy Commission hereby establishes the guaranteed minimum prices specified in paragraph (b) of this section, for the delivery to the Commission, in accordance with the terms of this section during the ten calendar years following its effective date, of domestic refined uranium, high-grade uranium-bearing ores and mechanical concentrates, in not less than the quantity and grade specified in paragraph (e) of this section. This guarantee does not apply to uranium-bearing ores of the Colorado Plateau area, commonly known as carnotite-type or roscoelite-type ores, prices for which are established by § 60.3.

NOTE: The term "domestic" in this section, referring to uranium, uranium-bearing ores and mechanical concentrates, means such uranium, ores, and concentrates produced from deposits within the United States, its territories, possessions and the Canal Zone.

(b) *Guaranteed minimum prices.* The following minimum prices are established:

(1) For uranium-bearing ores and mechanical concentrates, $3.50 per pound of U_3O_8 (uranium oxide) determined by the Commission to be recoverable, less cost per pound of refining such ores or concentrates to standards of purity required for

PUBLIC LAND ORDER 565, Dated February 25, 1949

COLORADO—NEW MEXICO PRINCIPAL MERIDIAN

T. 46 N., R. 17 W.,
Secs. 16 to 22, inclusive.

UTAH—SALT LAKE MERIDIAN

T. 36 S., R. 21 E.,
Secs. 19 to 23, inclusive; Secs. 26 to 35, inclusive.
T. 37 S., R. 21 E. (unsurveyed),
Secs. 2 to 11, inclusive; Secs. 13 to 30, inclusive.

PUBLIC LAND ORDER 698, Dated February 12, 1951

COLORADO—NEW MEXICO PRINCIPAL MERIDIAN

T. 46 N., R. 17 W.,
Sec. 15.
T. 47 N., R. 17 W.,
Sec. 3; Sec. 4, lots 1, 2, S½NE¼ and SE¼;
Secs. 9, 10, 11; Sec. 13, SW¼;
Secs. 14, 15, 16; Secs. 22 to 26, inclusive;
Sec. 35, E½; Sec. 36.
T. 48 N., R. 17 W.,
Secs. 1 to 28, inclusive; Sec. 29, N½;
Sec. 30, lots 1, 2, E½NW¼, and NE¼;
Secs. 34, 35, and 36.
T. 49 N., R. 17 W.,
Sec. 3; Secs. 7 to 11, inclusive;
Secs. 14 to 36, inclusive.
T. 50 N., R. 17 W.,
Sec. 28, W½; Sec. 33; Sec. 34, S½.
T. 48 N., R. 18 W.,
Secs. 1, 12, 13, and 24.

(3) the property must be certified by the Commission as eligible using the following criteria as guides:

(i) *Purpose of the bonus.* The purpose of the bonus is to encourage and assist the development of new sources of domestic uranium production.

(ii) *Character of mining property.* The mining property may consist of a placer or lode location, or if not covered by location, a tract which the Commission finds to be comparable or otherwise appropriate. However, an entire holding consisting of contiguous locations or tracts will be regarded as only a single eligible unit of mining property if the locations or tracts are held in common in the manner set forth in the following paragraph.

(iii) *Title or interest of the holder of the property.* The title or interest in the mining property should be one of ownership or lawful possession of mining rights. This type of holding will generally be that of an owner or leaser (lessee). It is recognized that there are various arrangements such as split check leases, piece rate contracts and the like whereby persons either as employees or independent contractors conduct mining operations on designated areas of property held by another who also supplies certain of the mining services or equipment or both and who receives in return a percentage of the proceeds of the ore produced. In the case of such arrangements, the person who grants the right to conduct these mining operations will be considered as the holder of the mining property although others perform mining operations on it.

(iv) *Minimum size of mining property.* The mining property, if it is made up of a location or locations, should contain at least 15 acres. The minimum size of lands on Indian reservations will be established by the Commission after consultation with the Bureau of Indian Affairs of the Department of Interior.

The minimum size of other mining properties will be established by the Commission in individual cases in the light of the purpose of the bonus.

(v) *Subdivision or consolidation of property.* Since the division of existing mining properties into smaller units might have the effect of increasing bonus payments without advancing the purpose of the bonus program, division of a single unit of mining property on or after March 1, 1951, will not be recognized in determining its eligibility for bonus payments under this section. In addition, consolidation or merger of contiguous mining properties on or after March 1, 1951, will not affect the eligibility of the separate properties for bonus payments.

(vi) *Special cases.* Since the above criteria are merely guides to assist the Commission in its decisions, areas which fail to meet all of the criteria may be certified by the Commission as eligible in special cases where it is determined that the deviations are not substantial or that their disqualification would cause serious inequities. In determining whether or not serious inequities would result, the physical characteristics and location of the deposit may be a factor. Under appropriate circumstances, a segment of a certified property may itself be certified as eligible. On the other hand, technical compliance with all the above criteria will not necessarily make a property eligible. Properties leased to private operators by the Commission will not be eligible for bonus payments except under special circumstances and as provided for in the lease.

(h) *Determination by the Commission.* The Commission expressly reserves the right to decide the amount of any bonus payments to be made, whether the property should be certified as an eligible mining property, the person to whom the bonus should be paid and whether for any reason a bonus is not payable. These decisions shall rest in the sole discretion of the

PUBLIC LAND ORDER 494, Dated July 7, 1948

COLORADO—NEW MEXICO PRINCIPAL MERIDIAN

T. 49 N., R. 17 W.,
Secs. 4, 5, and 6.
T. 50 N., R. 17 W.,
Sec. 7, Secs. 17 to 20, inclusive, and Secs. 29 to 32, inclusive.
T. 43 N., R. 18 W., (unsurveyed)
Sec. 5; Sec. 6, E½.
T. 44 N., R. 18 W.,
Sec. 19, SW¼; Sec. 29, SW¼, Sec. 30, NW¼ and SE¼;
Sec. 31, NE¼; Sec. 32, NW¼.
T. 50 N., R 18 W., (partly unsurveyed)
Secs. 2 to 6, inclusive;
Secs. 9 to 13, inclusive;
Sec. 14, NW¼.
T. 51 N., R. 18 W., (partly unsurveyed)
Secs. 19, 20, and 21;
Secs. 28 to 32, inclusive.
T. 43 N., R. 19 W.,
Sec. 19, lots 1, 2, 3, 4, E½W½.
T. 44 N., R. 19 W.,
Sec. 24, SE¼; Sec. 25, NE¼.
T. 43 N., R. 20 W.,
Sec. 23, SE¼; Sec. 24; Sec. 25, NW¼; Sec. 26, NE¼.

UTAH—SALT LAKE MERIDIAN

T. 24 S., R. 25 E.,
Secs. 24 to 27, inclusive; Secs. 34, 35, and 36.
T. 25 S., R. 25 E.,
Secs. 1, 2, 3, 10, 11, and 12 (unsurveyed).

As explained on page 52, certain public lands in Southwestern Colorado and Southeastern Utah have been withdrawn from entry and appropriation under the public land laws to assist the Atomic Energy Commission in carrying out its exploration drilling program. The lands withdrawn are described in Public Land Orders 459, 494, 565, and 698. Certain of the lands withdrawn under Orders 459 and 494 were restored to the public domain under Orders 565 and 698.

Lands in withdrawn status as of June 30, 1951, and the identifying land orders are as follows:

PUBLIC LAND ORDER 459, Dated March 25, 1948

COLORADO—NEW MEXICO PRINCIPAL MERIDIAN

T. 46 N., R. 17 W.,
Secs. 1, 2, and 12.
T. 47 N., R. 17 W.,
Sec. 4, lots 3, 4, S½NW¼ and SW¼;
Secs. 5 and 6; Sec. 7, NE¼; Sec. 8;
Secs. 17 to 21 inclusive; Secs. 27, 28 and 29;
Sec. 34; Sec. 35, W½.
T. 48 N., R. 17 W.,
Sec. 29, S½; Sec. 30, S½; Secs. 31, 32, and 33.
T. 43 N., R. 18 W., (partly unsurveyed)
Secs. 18, 19, 20, and Secs. 28 to 33, inclusive.
T. 43 N., R. 19 W.,
Sec. 8, S½; Sec. 10; Sec. 11, S½;
Sec. 13, E½; Secs. 14 to 18, inclusive;
Sec. 20, E½; Sec. 21, S½; Secs. 24 and 25;
Sec. 28; Sec. 29, E½.
T. 44 N., R. 19 W.,
Sec. 22, E½; Sec. 23, S½; Sec. 30, S½; Sec. 31, N½.

Commission and shall be final and conclusive. The Commission further reserves the right to establish procedures to carry out the bonus program. Any bonus payments made hereunder with respect to particular ores shall be the only such bonus payments made for those ores. The Commission will not consider any other application for bonus payments on those ores.

(i) *Application for certification.* Applications for certification of a property as eligible should be made to:

U. S. Atomic Energy Commission
Colorado Raw Materials Office
P. O. Box 270
Grand Junction, Colo.

The application should include a description of the mining property indicating its size, location, ownership, interest of the applicant, and public recording. There should also be included a statement by the applicant that to the best of his knowledge the total quantity of uranium oxide contained in ore accepted by stations or mills (or any other uranium ore processing plants) from that property between April 9, 1948, and February 28, 1951, inclusive, was less than 10,000 pounds. A form prescribed by the Commission and obtainable at a station or mill should be used for supplying the above information. Certification by the Commission will be a prerequisite to payment of the bonus, but after certification, payments will be made for ores which are delivered before certification and which meet the requirements of this section. Normally certification will not be made before uranium deposits have been discovered on the property, but the Commission may issue certifications prior to discovery in special cases. The Commission reserves the right to revoke a certification if it determines that its issuance was based on fraud, misrepresentation or mistake or if the requirements of this action are not complied with. The Commission

may require such information and right to make such inspections of the mining property as it finds necessary for the purpose of determining its eligibility for bonus payments and the amounts to be paid.

NOTE.—Misrepresentation or falsification of facts in an application for certification or for bonus payments may subject the offender to criminal penalties under pertinent provisions of the United States Code including Section 1001 of Title 18. Any such offenses also will disqualify the offender from receiving bonus payments.

(j) *Application for bonus payment.* Application for a bonus payment should be made on a prescribed form (obtainable at a station or mill) at intervals not more frequent than once a month during a period when ore deliveries from the property are believed to meet the requirements of this section. Applications may be addressed as follows:

U. S. Atomic Energy Commission
Colorado Raw Materials Office
P. O. Box 270
Grand Junction, Colorado

In addition to the application, the Commission may require such other information as it finds necessary.

(k) *Who may apply for bonus payments.* The person (other than a royalty payee or the like) who has lawfully received payment from a station or mill for the delivery of ore from a certified mining property may apply for bonus payments under this section. However, in special cases, the applications of persons whose ores have been accepted by the station or mill but for which payment is still pending will be considered.

(l) *Mill processing ores from its own mines.* In the event that an operator of a mill processes in the mill ores which it obtains from mining properties operated by it, the Commission

sums, including profits, as the Commission deems fair and reasonable for the discovery, mining, development, production, extraction, and other services performed with respect to such material prior to such delivery, but such payment shall not include any amount on account of the value of such material before removal from its place of deposit in nature. If the Commission does not require delivery of such material to it, the reservation hereby made shall be of no further force or effect."

2. The reservation required by paragraph 1 above need not be included in any disposition of land which is not in excess of one acre and which is devoted primarily to a residential use.

3. Executive Order No. 9701 of March 4, 1946, entitled "Providing for the Reservation of Rights to Fissionable Materials in Lands Owned by the United States," is hereby revoked; but such revocation shall not be construed to affect the revocation of Executive Order No. 9613 made by Executive Order No. 9701 or the provisions contained therein with respect to the lands released from withdrawal by the revocation of Executive Order No. 9613.

HARRY S. TRUMAN.

THE WHITE HOUSE,
December 5, 1947

the United States, except in conveyances where all minerals, including source material, are reserved to the United States; (b) all leases, permits, or other authorizations of whatever kind hereafter granted to remove minerals from such lands; and (c) all leases, permits, or other authorizations which otherwise would preclude the United States from exercising its right to enter upon the lands and prospect for, mine, and remove minerals, shall contain the following reservation:

"All uranium, thorium, and all other materials determined pursuant to section 5 (b) (1) of the Atomic Energy Act of 1946 (60 Stat. 761) to be peculiarly essential to the production of fissionable material, contained, in whatever concentration, in deposits in the lands covered by this instrument are hereby reserved for the use of the United States, together with the right of the United States through its authorized agents or representatives at any time to enter upon the land and prospect for, mine, and remove the same, making just compensation for any damage or injury occasioned thereby. However, such land may be used, and any rights otherwise acquired by this disposition may be exercised, as if no reservation of such materials had been made; except that when such use results in the extraction of any such material from the land in quantities which may not be transferred or delivered without a license under the Atomic Energy Act of 1946, as it now exists or may hereafter be amended, such material shall be the property of the United States Atomic Energy Commission, and the Commission may require delivery of such material to it by any possessor thereof after such material has been separated as such from the ores in which it was contained. If the Commission requires the delivery of such material to it, it shall pay to the person mining or extracting the same, or to such other person as the Commission determines to be entitled thereto, such

will pay the bonus under the conditions set forth in this section to the same extent as if the mining properties were operated by another person who delivered ore to the mill and received payment for it from the mill. In such case, however, the weights and assays used to fix the amount of payment due as a bonus under this section shall be determined in accordance with practices satisfactory to the Commission.

(m) *Definitions.* As used in this section,

(1) "Commission" means the Atomic Energy Commission created by the Atomic Energy Act of 1946, or its duly authorized representative.

(2) "person" means any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, or combination thereof. The term "person" shall not include the U. S. or any agency thereof or any officer or employee of the Commission.

(n) *Commission ore-buying stations and qualified uranium mills.*

(1) *Stations.* The following are Commission ore-buying stations (that is, ore-buying stations operated on behalf of the Commission):

American Smelting & Refining Co.
Monticello, Utah

American Smelting & Refining Co.
Marysvale, Utah

(2) *Mills.* The following are qualified uranium mills:

United States Vanadium Co.
Uravan, Colo.

United States Vanadium Co.
Rifle, Colo.

Climax Uranium Co.
Grand Junction, Colo.

Vanadium Corporation of America
Durango, Colo.

Vanadium Corporation of America
Naturita, Colo.

Vanadium Corporation of America
Hite, Utah

Vitro Chemical Co.
600 West 33d St. South
Salt Lake City, Utah

(3) *Modifications.* These lists may be modified from time to time by public announcement of the Commission.

(o) *Inquiries and communications.* Inquiries about this section and all other communications should be addressed as follows:

U. S. Atomic Energy Commission
Colorado Raw Materials Office
P. O. Box 270
Grand Junction, Colo.

(p) *Records, rules and regulations.* The Commission may require applicants for bonus payments under this section to keep for Commission inspection such records concerning production and deliveries of uranium ores for which application is made as it finds proper and may issue such additional rules and regulations relating to bonus payments as it finds necessary or desirable.

(60 Stat. 755–775; 42 U. S. C. 1801–1819.)

Dated at Washington, D. C., this 27th day of June 1951.

By order of the Commission.

M. W. Boyer,
General Manager.

reservation of such materials had been made under this subsection; except that, when such use results in the extraction of any such material from the land in quantities which may not be transferred or delivered without a license under this subsection, such material shall be the property of the Commission and the Commission may require delivery of such material to it by any possessor thereof after such material has been separated as such from the ores in which it was contained. If the Commission requires the delivery of such material to it, it shall pay to the person mining or extracting the same, or to such other person as the Commission determines to be entitled thereto, such sums, including profits, as the Commission deems fair and reasonable for the discovery, mining, development, production, extraction, and other services performed with respect to such material prior to such delivery, but such payment shall not include any amount on account of the value of such material before removal from its place of deposit in nature. If the Commission does not require delivery of such material to it, the reservation made pursuant to this paragraph shall be of no further force or effect.

EXECUTIVE ORDER 9908

RESERVATION OF SOURCE MATERIAL IN CERTAIN LANDS OWNED BY THE UNITED STATES

By virtue of the authority vested in me as President of the United States, and in further effectuation of the policies declared by section 1 of the Atomic Energy Act of 1946 (60 Stat. 755), it is hereby ordered as follows:

1. So far as not in conflict with existing law, (a) all disposals of lands, other than public lands heretofore or hereafter acquired by the United States or any instrumentality thereof, including lands in the Territories and possessions of

(7) PUBLIC LANDS. All uranium, thorium, and all other materials determined pursuant to paragraph (1) of this subsection to be peculiarly essential to the production of fissionable material, contained, in whatever concentration, in deposits in the public lands are hereby reserved for the use of the United States subject to valid claims, rights, or privileges existing on the date of the enactment of this Act: *Provided, however*, That no individual, corporation, partnership, or association, which had any part, directly or indirectly, in the development of the atomic bomb project, may benefit by any location, entry, or settlement upon the public domain made after such individual, corporation, partnership, or association took part in such project, if such individual, corporation, partnership, or association, by reason of having had such part in the development of the atomic bomb project, acquired, confidential official information as to the existence of deposits of such uranium, thorium, or other materials in the specific lands upon which such location, entry, or settlement is made, and subsequent to the date of the enactment of this Act made such location, entry, or settlement or caused the same to be made for his, its, or their benefit. The Secretary of the Interior shall cause to be inserted in every patent, conveyance, lease, permit, or other authorization hereafter granted to use the public lands or their mineral resources, under any of which there might result the extraction of any materials so reserved, a reservation to the United States of all such materials, whether or not of commercial value, together with the right of the United States through its authorized agents or representatives at any time to enter upon the land and prospect for, mine, and remove the same, making just compensation for any damage or injury occasioned thereby. Any lands so patented, conveyed, leased, or otherwise disposed of may be used, and any rights under any such permit or authorization may be exercised, as if no

APPENDIX 4

UNITED STATES ATOMIC ENERGY COMMISSION LICENSING REGULATIONS

GENERAL PROVISIONS

§ 40.1 *Basis and purpose.* The regulations in this part, for the control of source material essential to the production of fissionable material, are promulgated by the United States Atomic Energy Commission pursuant to the Atomic Energy Act of 1946 (60 Stat. 755) in order to assure adequate source material for production, research, and development activities and to prevent the use of such material in a manner inconsistent with the national welfare.

§ 40.2 *Definitions.* (a) As used in this part, the term "source material" means any material, except fissionable material, which contains by weight one-twentieth of one percent (0.05 percent) or more of (1) uranium, (2) thorium, or (3) any combination thereof.

(b) "Fissionable material" means fissionable material as defined in section 5 of the Atomic Energy Act of 1946 and regulations which may be issued pursuant to that act by the Commission.

(c) "Raw source material" means (1) source material which has not been chemically processed in any manner and (2) source material in the form of residues or tailings.

(d) "Refined source material" means source material other than raw source material.

(e) "Person" means any individual, corporation, partnership firm, association, trust, estate, public or private institution, group, the United States or any agency thereof, any government

other than the United States, any political subdivision of any such government, and any legal successor, representative, agent, or agency of the foregoing, or other entity, but shall not include the Commission or officers or employees of the Commission in the exercise of duly authorized functions.

(f) "The United States," when used in a geographical sense, includes all territories and possessions of the United States and the Canal Zone.

(g) "Commission" means the Atomic Energy Commission created by the Atomic Energy Act of 1946, or its duly authorized representative.

TRANSFER OF SOURCE MATERIAL

§ 40.10 *Restriction on transfers.* Unless authorized by a license issued by the Commission, no person may transfer or deliver, receive possession of or title to or export from the United States, any source material after removal from its place of deposit in nature. This includes the disposition of raw source material (including residues or tailings) by dumping into streams or sewers, or disposition in such other manner that recovery cannot be made. The restriction of this section does not apply to any transfer, delivery, or receipt of possession or title exempted by § 40.11.

§ 40.11 *Exempted transfers.* Except where export is intended or where export occurs, the restriction of § 40.10 does not apply to any transfer, delivery, or receipt of possession or title, of the following:

(a) During any single calendar month a quantity of raw source material after removal from its place of deposit in nature which contains less than 10 pounds of uranium or thorium or any combination thereof, or

(b) Products listed in Schedule I (§ 40.60).

regulations or orders requiring reports of ownership, possession, extraction, refining, shipment, or other handling of source materials as it may deem necessary, except that such reports shall not be required with respect to (A) any source material prior to removal from its place of deposit in nature, or (B) quantities of source materials which in the opinion of the Commission are unimportant or the reporting of which will discourage independent prospecting for new deposits.

(5) ACQUISITION. The Commission is authorized and directed to purchase, take, requisition, condemn, or otherwise acquire, supplies of source materials or any interest in real property containing deposits of source materials to the extent it deems necessary to effectuate the provisions of this Act. Any purchase made under this paragraph may be made without regard to the provisions of section 3709 of the Revised Statutes (U. S. C., title 41, sec. 5) upon certification by the Commission that such action is necessary in the interest of the common defense and security, or upon a showing that advertising is not reasonably practicable, and partial and advance payments may be made thereunder. The Commission may establish guaranteed prices for all source materials delivered to it within a specified time. Just compensation shall be made for any property taken, requisitioned, or condemned under this paragraph.

(6) EXPLORATION. The Commission is authorized to conduct and enter into contracts for the conduct of exploratory operations, investigations, and inspections to determine the location, extent, mode of occurrence, use, or conditions of deposits or supplies of source materials, making just compensation for any damage or injury occasioned thereby. Such exploratory operations may be conducted only with the consent of the owner, but such investigations and inspections may be conducted with or without such consent.

APPENDIX 6

LAWS AND SPECIAL ORDERS

Atomic Energy Act of 1946 (Public Law 585—79th Congress)

PROVISIONS AFFECTING SOURCE MATERIALS

Sec. 5 (b) SOURCE MATERIALS.

(1) DEFINITION. As used in this Act, the term "source material" means uranium, thorium, or any other material, which is determined by the Commission, with the approval of the President, to be peculiarly essential to the production of fissionable materials; but includes ores only if they contain one or more of the foregoing materials in such concentration as the Commission may by regulation determine from time to time.

(2) LICENSE FOR TRANSFERS REQUIRED. Unless authorized by a license issued by the Commission, no person may transfer or deliver, receive possession of or title to, or export from the United States any source material after removal from its place of deposit in nature, except that licenses shall not be required for quantities of source materials which, in the opinion of the Commission, are unimportant.

(3) ISSUANCE OF LICENSES. The Commission shall establish such standards for the issuance, refusal, or revocation of licenses as it may deem necessary to assure adequate source materials for production, research, or development activities pursuant to this Act or to prevent the use of such materials in a manner inconsistent with the national welfare. Licenses shall be issued in accordance with such procedures as the Commission may by regulation establish.

(4) REPORTING. The Commission is authorized to issue such

§ 40.20 *Applications for licenses.* Applications for licenses to transfer or deliver, receive possession of or title to, or export source material shall be filed with the United States Atomic Energy Commission, P. O. Box 30, Ansonia Station, New York 23, New York. Applications should be filed on Form AEC–2, copies of which are available at the above address. When it is impracticable to use this form, applications may be made by letter or telegram, giving the information required by Form AEC–2.

§ 40.21 *Issuance of licenses.* Upon a determination that an application meets the requirements of the Atomic Energy Act of 1946 and of the regulations of the Commission, the Commission will issue a license in such form and upon such conditions as it deems appropriate and in accordance with law.

§ 40.22 *Standards for issuance of licenses.* In making the determination mentioned in § 40.21, the Commission will be guided by the following standards:

(a) Assurance of the common defense and security;

(b) Assurance of adequate source materials for production, research, and development;

(c) Prevention of the use of source materials in a manner inconsistent with the national welfare;

(d) Preservation of health and safety.

So far as consistent with these standards, licenses will be granted upon conditions that will not interfere with the conduct of normal business activities. No license will be issued to any person if to do so would, in the opinion of the Commission, be inimical to the common defense and security.

§ 40.23 *Types of licenses.* Licenses are of two basic types, general and specific. General licenses are issued to an identified class of persons who are not designated by name, such as common or contract carriers, retail druggists or physicians, and others,

to permit transfers of source material under specified conditions without the filing of an application with the Commission. General licenses now in effect are set out in Schedule III (§ 40.62). Specific licenses are issued to named persons in response to applications filed with the Commission. Specific licenses may authorize a continuing activity or, as in the case of exports, may be limited to an individual transaction. So far as consistent with the purposes of the Atomic Energy Act of 1946, licenses will be tailored to fit the normal business requirements of the licensee.

§ 40.24 *Conditions of licenses.* Each license will require the licensee to comply with certain conditions, including the filing of reports with the Commission and restrictions upon the use of source material. Willful failure of a licensee to file any such report which truthfully sets forth all information required, or willful failure to comply with any other condition of the license, shall constitute a violation of the regulations in this part.

§ 40.25 *Revocation, suspension, modification of licenses.* Any license may be modified, withdrawn, suspended, revoked, or annulled at any time in the discretion of the Commission upon a determination by the Commission that the public health, interest or safety requires such action or that the licensee has willfully failed to comply with any condition of the license. In the absence of such a determination, no modification, withdrawal, suspension, revocation, or annulment of any license will be made except upon application therefor by the licensee or unless, prior thereto, facts or conduct warranting such action have been called to the attention of the licensee in writing and the licensee has been accorded opportunity to demonstrate or achieve compliance with all lawful requirements. Nothing in this part shall limit the authority of the Commission to issue or amend its regulations in accordance with law.

whose locations antedates the homestead filing, must protest such filing in order to protect his title to the surface of his mining claim.

26. *Cost of patent proceedings for mining claims.* With the exception of the fixed charges, such as the fee for filing an application for patent, which is $10, the purchase price of lands in lode claims and millsites at $5 per acre, and $5 for each fractional part of an acre, and $2.50 per acre or fraction of an acre for placer lands, unless otherwise provided by law as to certain lands, no estimate can be furnished as to what it will cost to procure a patent. The cost of publication, survey, and abstract of title depends upon the services rendered and vary in each case.

FRED W. JOHNSON,
Director.

21. *The United States mining laws are applicable to the following States:* Arizona, Arkansas, California, Colorado, Florida, Idaho, Louisiana, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming; also in the Territory of Alaska.

22. *National parks and monuments:* With the exception of Mount McKinley National Park and Glacial Bay National Monument in Alaska, Organ Pipe Cactus National Monument in Arizona, and Death Valley National Monument in California, mining locations may not be made on lands in national parks and monuments after their establishment.

23. *Withdrawals.* Withdrawals usually bar location under the mining laws, but withdrawals made under the act of June 25, 1910 (36 Stat. 847), as amended by the act of August 24, 1912 (37 Stat. 497), permit locations of the withdrawn lands containing metalliferous minerals. Lands withdrawn for water power purposes are not subject to location unless first restored under the provisions of section 24 of the Federal Water Power Act.

24. *Minerals in Indian lands.* In general, the mineral deposits in Indian reservations are subject to leasing and are under the administration of the Office of Indian Affairs.

25. *Mineral land in agricultural entries—Protest—Contest.* Where lands known to be valuable for minerals are embraced in an agricultural filing, other than a stock raising homestead filing, a mineral claimant may initiate a contest thereagainst by filing a protest sworn to and in duplicate, in the local land office, alleging sufficient facts, which, if proven, will establish the mineral character of the land, and warrant cancellation of the agricultural filing. The protest must be corroborated by one or more witnesses having knowledge of the facts alleged. In the case of stock raising homestead entries, a mineral claimant,

§ 40.26 *Renewal of licenses.* In any case in which a licensee has filed an application in proper form for a renewal or a new license not less than 30 days prior to expiration of his existing license, such existing license, to the extent that it has reference to any activity of a continuing nature, shall not expire until the application for a renewal or a new license has been finally determined by the Commission.

§ 40.27 *Transfer of licenses.* Licenses shall be nontransferable.

§ 40.28 *Licenses to transfer uranium for certain uses.* Unless justified by exceptional circumstances licenses will not be issued for transfers of source material which contains by weight uranium in excess of one-twentieth of one percent (0.05%) for use in the manufacture of or for incorporation in any of the products listed in Schedule II (§ 40.61).

§ 40.29 *Control or possession of source material by persons who do not hold specific or general licenses.* (a) Any person who has, or who hereafter obtains, possession of or title to (1) a quantity of raw source material after removal from its place of deposit in nature which contains 10 pounds or more of uranium, thorium, or any combination thereof, or (2) a quantity of refined source material which contains 1 pound or more of uranium, thorium, or any combination thereof (except refined source material incorporated in products listed in Schedule I (§ 40.60)) shall, not later than 30 days after the effective date of the regulations in this part or after the date of obtaining such possession or title, whichever is later, file with the Commission a reasonably detailed statement of:

(i) The nature of the material,
(ii) Its quantity,
(iii) Its uranium and thorium content,
(iv) Its location, and
(v) Its ownership.

(b) The requirement in paragraph (a) of this section does not apply to any person who holds a specific or general license from the Commission.

REPORTS

§ 40.30 *Reports.* Reports, in addition to those called for in licenses, may be required by the Commission from time to time, subject to approval by the Bureau of the Budget in certain cases, with respect to the ownership, possession, extraction, refining, shipment, or other handling of source material after removal from its place of deposit in nature, as the Commission may deem necessary.

NOTE: The reporting requirements hereof have been approved by the Bureau of the Budget pursuant to the Federal Reports Act of 1942.

VIOLATIONS

§ 40.40 *Penalties for violations.* A violation of the regulations in this part shall be deemed to be a violation of the Atomic Energy Act of 1946 and shall subject the violator to the penalties therein prescribed. In addition, the Commission may take such action with respect to source material involved in any violation as it deems appropriate and in accordance with law.

INTERPRETATIONS, PETITIONS, AND COMMUNICATIONS

§ 40.50 *Valid interpretations.* Except as specifically authorized by the Commission, no interpretation or explanation of the meaning of the regulations in this part issued by any officer or employee of the Commission other than one issued by the General Counsel in writing will be recognized to be valid and binding upon the Commission.

§ 40.51 *Petitions.* Petitions for relief from any restriction imposed under the regulations in this part may be made by filing

notice of the application, are stayed to await the outcome of the court proceedings.

19. *Coowners.* A coowner not named in the application for patent cannot assert his rights by filing an adverse claim, a protest being proper to cause his alleged rights to be considered when the case is adjudicated. If a coowner fails to do his proper proportion of annual assessment work on a claim, or fails to contribute his proportion of the cost thereof, the coowners who have caused the work to be done during any assessment period may, at the expiration of the assessment year, give such delinquent coowner personal notice in writing, or notice by publication in a newspaper published nearest the claim for at least once a week for 90 days, and if at the expiration of 90 days after such notice in writing, or 180 days after the first newspaper publication, such delinquent should fail to contribute his proportion of the expense required, his interest in the claim becomes the property of his coowners who have made the expenditure.

20. *Lode in placer.* If a placer mining applicant fails to state that there is a known lode within the boundaries of the claim, it is taken as a conclusive declaration that he has no right of possession thereto. If no such vein or lode be known the placer patent will convey all valuable mineral and other deposits within the boundaries of the claim. A known lode not included in an application for patent to the claim may be applied for even after issuance of patent to the placer mining claim. Where a placer mining claimant makes application for a placer containing within its boundaries a lode claim owned by him the lode must be surveyed, the lode being paid for on the basis of $5 per acre and the remaining portions of the placer at the rate of $2.50 per acre.

in the district land office. Information as to patent procedure can be obtained from the manager of the local land office or from the Bureau of Land Management. In general, a survey must be applied for unless the claim is a placer claim located by legal subdivisions, the application for survey to be made to the public survey office in the State wherein the claim is situated. Applications for patent are filed in the district land office. A notice of the application is required to be posted on the land prior to filing the application and to be published by the register after the application is filed.

16. *Blank forms.* No set form of location notices nor of the papers filed in patent proceedings for mining claims is required and no blank forms are furnished by the Bureau of Land Management or by the district land offices, for use in mineral cases. Forms containing essentials are printed by local private parties or concerns. The managers of the local land offices can usually advise you where such forms may be obtained.

17. *Common improvements.* An improvement, made upon one of a group of contiguous claims (cornering is not contiguity) owned in common, may be applied to such claims of the group, in existence at the time the improvement is made, shown to be benefited thereby.

18. *Adverse claims.* An adverse claim may be filed during the period of publication of notice of an application for patent (or within 8 months after the expiration of the publication period in Alaska), by one claiming a possessory right under another mining location to all or some portion of the land applied for, and must show fully the nature, boundaries, and extent of the area in conflict, to be followed, within 30 days after filing (60 days in Alaska), by suit in a court of competent jurisdiction. If suit is filed, all proceedings on the application, except the filing of the affidavits of continuous posting and publication of the

a letter, in duplicate, with the United States Atomic Energy Commission, Post Office Box 30, Ansonia Station, New York 23, New York, stating the reasons why the petition should be granted.

§ 40.52 *Communications.* All communications concerning the regulations of this part or any license issued under them should be addressed to the United States Atomic Energy Commission, P. O. Box 30, Ansonia Station, New York 23, New York.

§ 40.53. *Right to Require Deliveries Reserved.* No license granted under the regulations in this part shall be deemed to constitute a waiver of the Commission's right to require delivery of source material to it under the conditions stated in Section 5 (b) (7) of the Atomic Energy Act of 1946 (60 Stat. 755).

SCHEDULES

§ 40.60 *Schedule I: Exempted products* (see § 40.10 and § 40.29).

(a) Incandescent mantles.

(b) Ceramic products.

(c) Refractories.

(d) Glass products.

(e) Photographic film, negatives and prints.

(f) Rare earth metals and compounds, mixtures and products containing not more than 0.25 percent by weight thorium, uranium, or any combination of these.

(g) Vacuum tubes.

(h) Thoriated tungsten containing not more than 3 percent by weight thorium.

§ 40.61 *Schedule II: Prohibited uses of uranium* (see § 40.28).

(a) Ceramic products.

(b) Glass products.

(c) Photographic films, negatives, and prints.

§ 40.62 *Schedule III: General licenses* (see § 40.23). Transfers, deliveries and receipts of possession of or title to source material, except where export is intended or where export occurs, which are within any one or more of the following categories, are hereby generally licensed:

(a) Transfers, deliveries and receipts of possession of (but not of title to) source material by contractors and agents of the Commission in the authorized course of their business for the Commission:

NOTE: The term "person" as defined in section 18 (c) of the Atomic Energy Act of 1946 and in § 40.2 does not include the Commission or officers or employees of the Commission in the exercise of duly authorized functions. Consequently, the restriction on transfers in § 40.10 does not apply in such cases.

(b) Transfers, deliveries and receipts of possession of (but not of title to) source material by common or contract carriers for transportation purposes only in the regular course of business;

(c) Transfers, deliveries and receipts of possession of and title to a quantity of refined source material which contains less than one pound of uranium, thorium, or any combination thereof, from or to any one person during any single calendar month, to the extent that the transaction consists of either:

(1) Transfer to or receipt of possession or title by a licensed dispensing pharmacist solely for the compounding of medicinals for delivery to consumers, or

(2) Transfer to or receipt of possession or title by a physician or consumer for medicinal purposes only, and not for resale, or

annual assessment period commencing at 12 o'clock noon on the 1st day of July succeeding the date of location. Failure to perform the assessment work for any year will subject the claim to relocation, unless work for the benefit of the claim is resumed before a relocation is made. The determination of the question of the right of possession between rival or adverse claimants to the same mineral land is committed exclusively to the court. (See 18.) However, failure to perform the annual assessment work on a mining claim in Alaska works a forfeiture of the claim, and resumption of work on the claim will not prevent relocation.

13. *Expenditures on claim for patent purposes—Lode—Placer—Mill site.* Five hundred dollars in labor or improvements of a mining nature, must be expended upon or for the benefit of each lode or placer claim, and compliance with the United States mining laws made otherwise, to entitle the claimant to prosecute patent proceedings therefor. Such expenditures must be completed prior to the expiration of the period during which notice of the patent proceedings is published. Patent expenditures on a mill site are not required, but it must be shown that the mill site is used or occupied for mining or milling purposes at the time an application for patent therefor is filed.

14. *Patent not necessary.* One may develop, mine, and dispose of mineral in a valid mining location without obtaining a patent, but possessory right must be maintained by the performance of annual assessment work on the claim in order to prevent its relocation by another.

15. *Procedure to obtain patent to mining claims.* The owner or owners of a valid mining location, or group of locations, on which not less than $500 has been expended on or for the benefit of each claim, may institute patent proceedings therefor

ing minors who have reached the age of discretion and corporations organized under the laws of any State. Agents may make locations for qualified locators.

8. *Number of locations.* The United States mining laws do not limit the number of locations that can be made by an individual or association.

9. *Valid locations—Discovery after conveyance.* A location is not valid until an actual discovery of mineral is made within the limits thereof. A placer location of more than 20 acres, made by two or more locators and conveyed to a less number before discovery is made, is valid to the extent of 20 acres only for each owner at date of discovery.

10. *Locations to be marked on ground—Notice.* Except placer claims described by legal subdivision, all mining claims must be distinctly marked on the ground so that their boundaries may be readily traced, and all notices must contain the name or names of the locators, the date of location and such a description of the claim by reference to some natural object or permanent monument as will serve to identify the claim.

11. *Locations on streams and bodies of water.* Beds of navigable waters are subject to the laws of the State in which they are situated and are not locatable under the United States mining laws. Title to the beds of meandered nonnavigable streams is in the riparian owner. The beds of unmeandered, nonnavigable streams are subject to location under the United States mining laws if they are unoccupied, as are also the beds of meandered nonnavigable streams when the abutting upland is unappropriated.

12. *Maintenance—Annual assessment work—Adverse claim—Jurisdiction.* The right of possession to a valid mining claim is maintained by the expenditure annually of at least $100 in labor or improvements of a mining nature on the claim, the first

(3) Transfer to or receipt of possession or title by an educational institution or hospital for educational or medical purposes only, and not for resale.

§ 40.70 *Effective date.* The regulations in this part shall become effective at midnight, March 31, 1947. This effective date, which is less than thirty days subsequent to publication, is found necessary and appropriate by the Commission in view of the fact that controls on transfers of source material exercised by the Civilian Production Administration under the Second War Powers Act will lapse at midnight, March 31, 1947.

Dated at Washington, D. C., this 17th day of March, 1947.

By order of the Commission.

DAVID E. LILIENTHAL,
Chairman.

(As amended F. R. Doc. 49-1930; Filed March 14, 1949; 8:50 A. M.)

APPENDIX 5

UNITED STATES DEPARTMENT OF THE INTERIOR, BUREAU OF LAND MANAGEMENT

Circular No. 1278

INFORMATION IN REGARD TO MINING CLAIMS ON THE PUBLIC DOMAIN

The purpose of this circular is to furnish brief information pertinent to the location and purchase of mining claims under the United States mining laws.

1. *Initiation of rights to mineral land.* Rights to mineral lands, owned by the United States, are initiated by prospecting for minerals thereon, and, upon the discovery of mineral, by locating the lands upon which such discovery has been made. A location is made by staking the corners of the claim, posting notice of location thereon (see 10), and complying with the State laws, regarding the recording of the location in the county recorder's office, discovery work, etc.

2. *State mining laws.* As supplemental to the United States mining laws there are State statutes relative to location, manner of recording of mining claims, etc., in the State, which should also be observed in the location of mining claims. Information as to State laws can be obtained locally or from State officials.

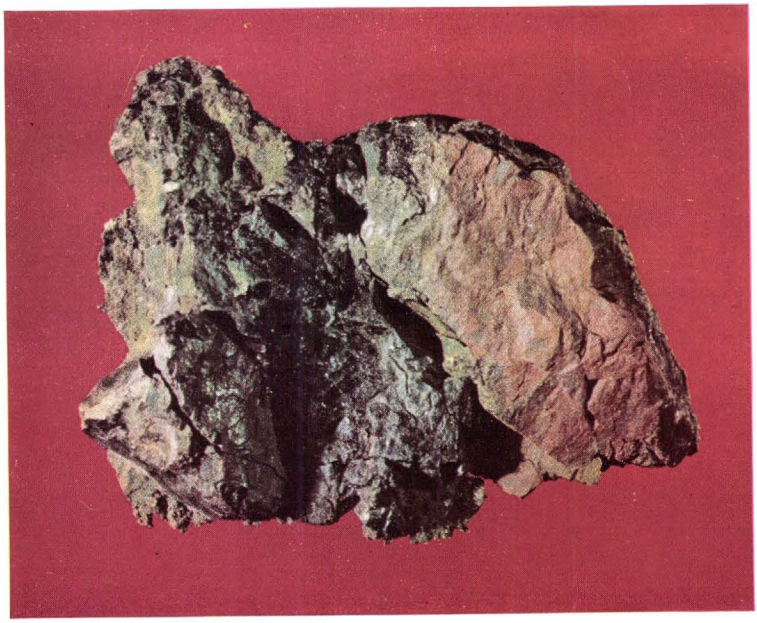
3. *Lands subject to location and purchase.* Vacant public surveyed or unsurveyed lands are open to prospecting, and upon discovery of mineral, to location and purchase, as are also lands in national forests in the public-land States (forest regulations must be observed), lands entered or patented under the stock raising homestead law (title to minerals only can be acquired), lands entered under other agricultural laws but not perfected, where prospecting can be done peaceably, and lands within the railroad grants for which patents have not issued.

4. *Status of lands.* Information as to whether any particular tract of land is shown by the records to be vacant and open to prospecting may be obtained from the manager of the land district in which the tract is situated. Since location notices of mining claims are filed in the office of the county recorder, ordinarily no information regarding unpatented mining claims is obtainable from the district land office or the Bureau of Land Management unless application for patent has been filed.

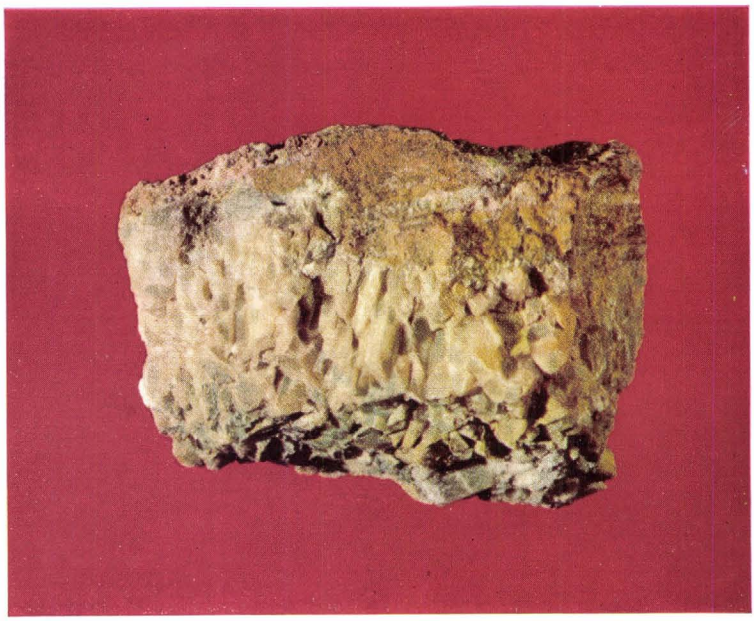
5. *Minerals subject to location.* Whatever is recognized as a mineral by the standard authorities, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof, is treated as coming within the purview of the mining laws. Deposits of coal, oil, gas, oil shale, sodium, phosphate, potash, and in Louisiana and New Mexico sulphur, belonging to the United States, can be acquired under the mineral leasing laws, and are not subject to location and purchase under the United States mining laws.

6. *Mining locations—Areas.* Lode locations for minerals discovered in lode or vein formation may not exceed in length 1,500 feet along the vein and in width 300 feet on each side of the middle of the vein, the end lines of the location to be parallel to each other. Placer locations, which include all minerals not occurring in vein or lode formation, may be for areas of not more than 20 acres for each locator, no claim to exceed 160 acres made by not less than eight locators. Placer locations must conform to the public surveys wherever practicable.

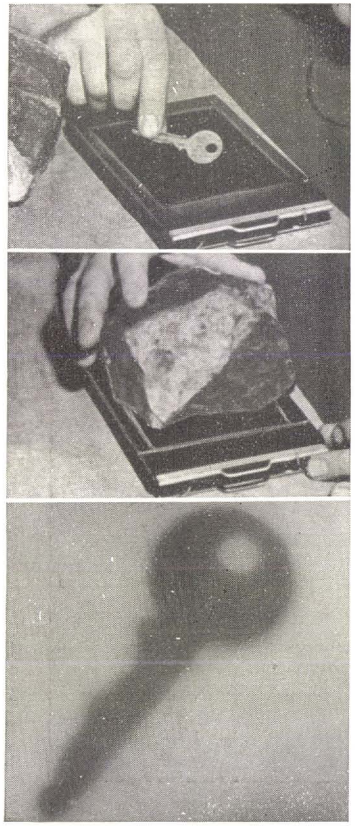
7. *Who may make locations.* Citizens of the United States, or those who have declared their intention to become such, includ-



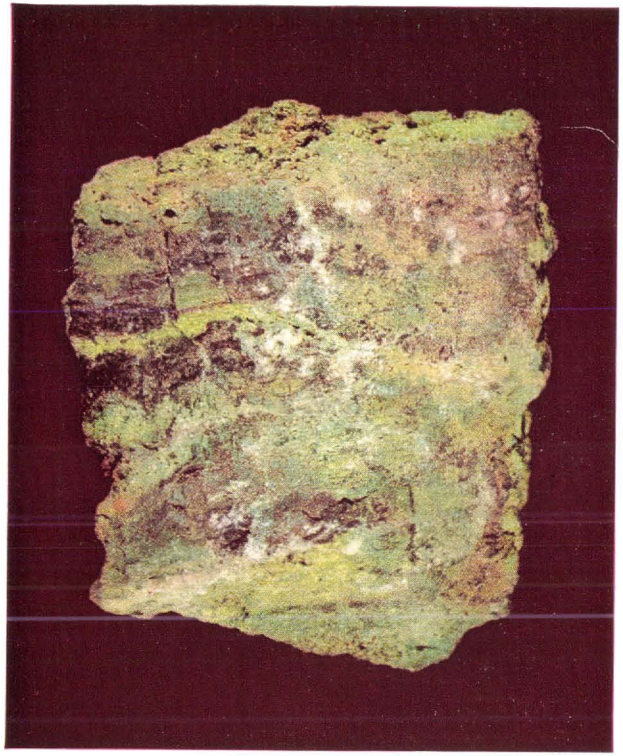
Pitchblende—Great Bear Lake, Canada



Carnotite And Uranophane Associated With Calcite—Grants, New Mexico

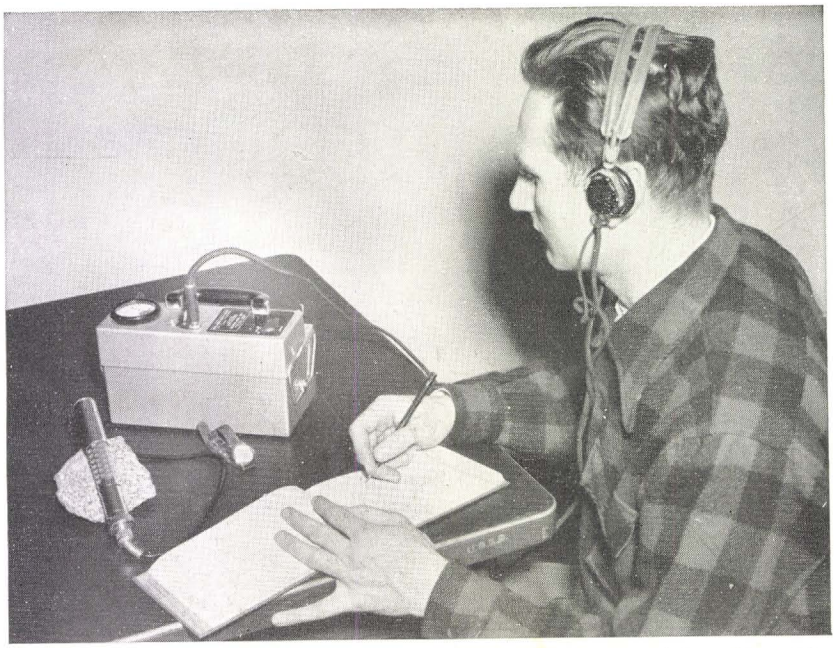


The technique for making a photographic test for radioactivity is illustrated here. At top, a key is placed on an unexposed photographic plate. Center, a rock sample is placed on top of the key. If the sample is primarily pitchblende, the developed film will produce a picture similar to that below after a 24-hour exposure. Less radioactive minerals will take longer periods of time.

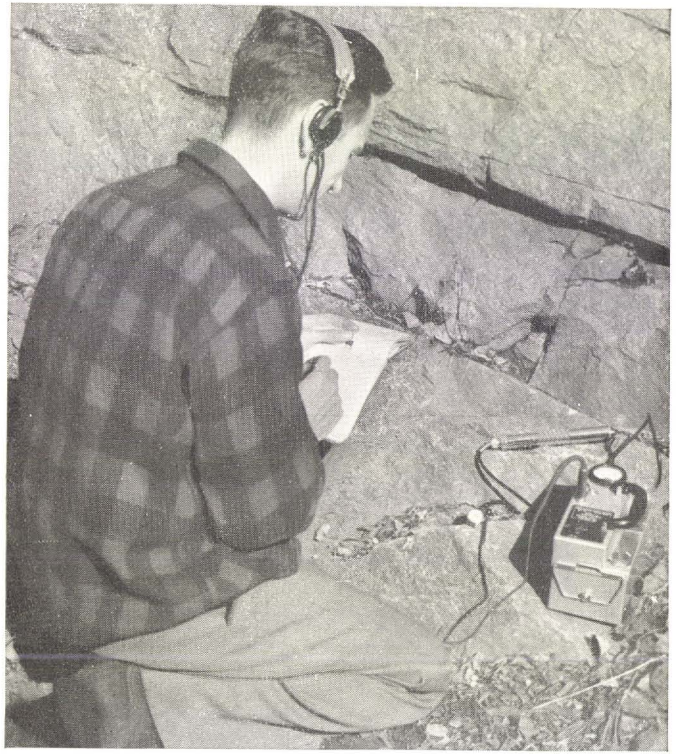


Pitchblende Associated With Copper Minerals—Happy Jack Mine, Utah

Autunite—Marysvale, Utah

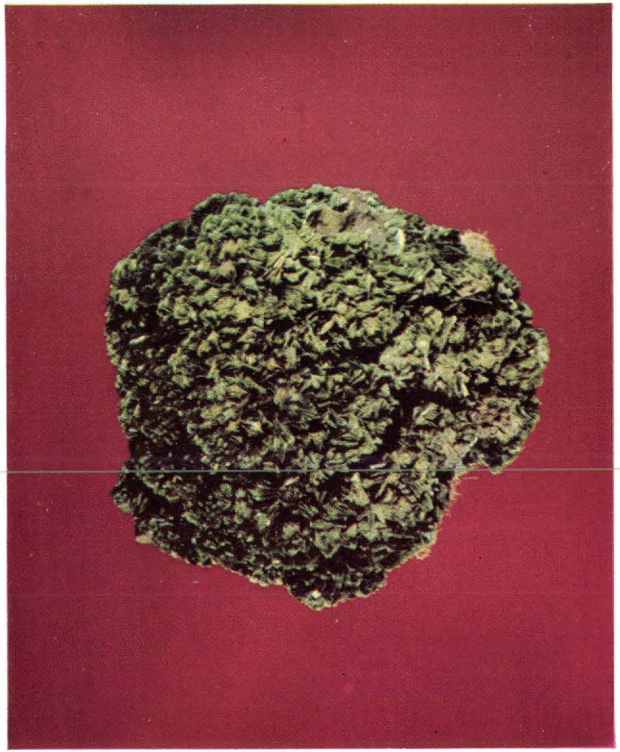


A prospector makes a Geiger counter test to obtain a rough assay of the radioactivity of a rock sample. Note the equipment used in making the test.

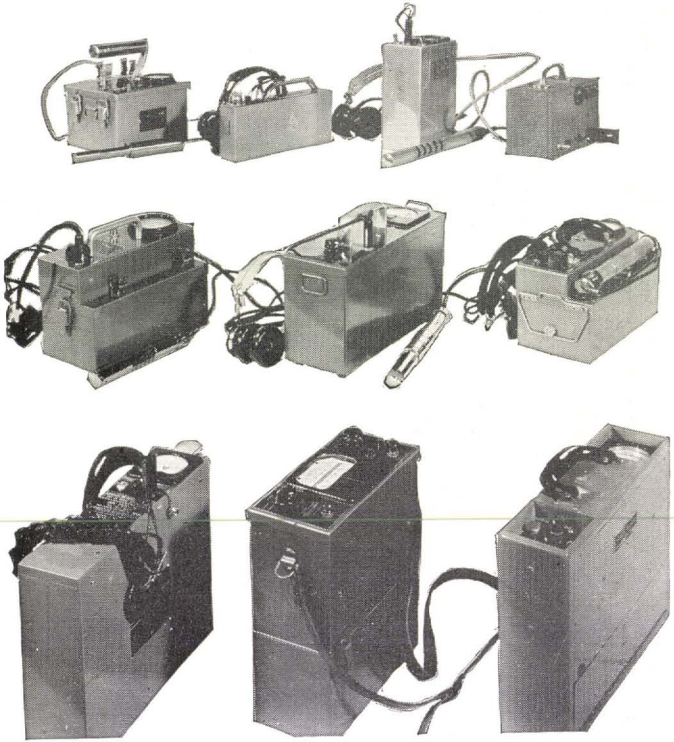


A prospector uses his Geiger counter to determine the radioactivity of a specific point in a generally radioactive area. A background count was taken before this specific reading was made.

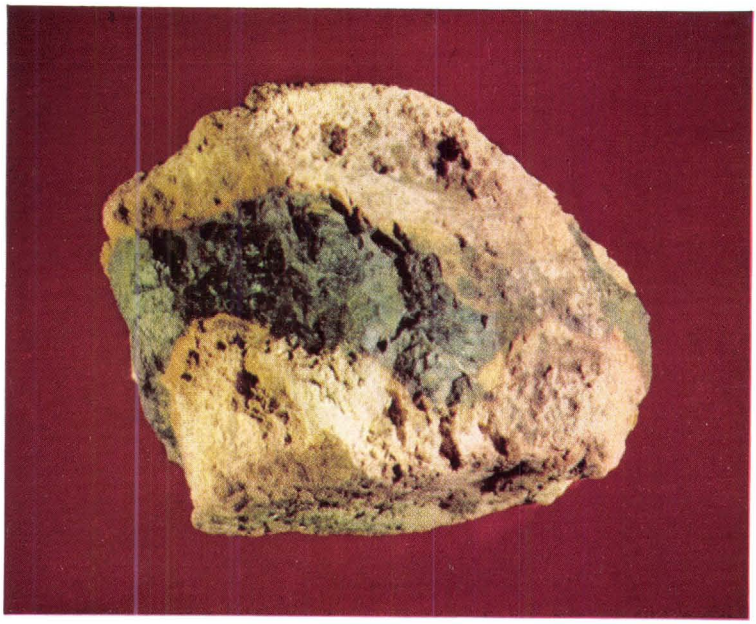
Carnotite—Colorado Plateau



Torbernite—Shinkolobwe Mine, Belgian Congo

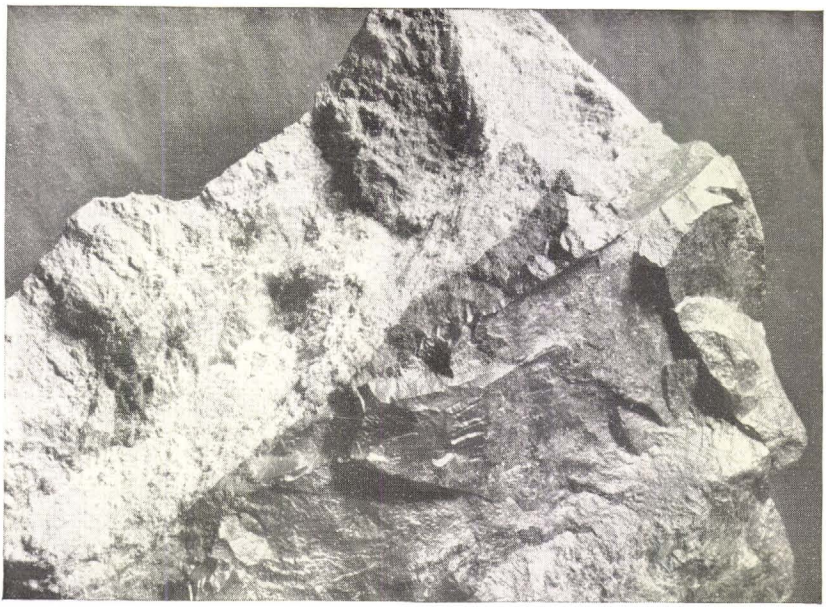


Field-type Geiger counters. There are a number of different types of portable Geiger counters. The prospector should consult manufacturers' catalogues before selecting a particular model, in order to find the counter that will best suit his individual needs.



Pitchblende With Alteration Products—Shinkolobwe Mine, Belgian Congo

Pitchblende-Bearing Vein Material—Lake Athabaska, Canada



A sample of uranium ore taken from a vein deposit at the Eldorado mine, Great Bear Lake, Canada. The dark-colored mineral in the lower two-thirds of the sample is pitchblende; the light-colored material is wall rock.

URANIUM MINING AND PROCESSING

AT KERR-McGEE'S GRANTS, NEW MEXICO OPERATIONS

KERR-McGEE CORPORATION

Litho U.S.A. P722-5M

During precipitation, the uranium solution is constantly agitated to keep the solid particles of uranium in suspension.

Leaving the precipitation circuit, the uranium, now in suspension rather than solution, is pumped to a thickener tank where the solid uranium particles are allowed to settle to the bottom of the tank.

From the bottom of the product thickener tank the precipitated uranium in the form of a slurry (about 50 percent solids) is pumped to a three-stage drum filter circuit. Moving through the filter circuit, the uranium is thoroughly washed to remove any soluble salts that might be entrained in the product.

The uranium leaves the last washing filter in the form of a filter cake. It is dropped onto a perforated plate where a roller pushes the material through the openings into spaghetti-like particles. The material in this form is fed to the Proctor Schwartz dryer.

In the dryer the product is dried by steam heat and is ready for packaging. The final product containing 80-83 percent uranium oxide is packaged in 55-gallon drums for shipment.

In addition to producing uranium oxide, the Kerr-McGee mill makes sulfuric acid (H_2SO_4) for use in the mill's leaching and stripping circuits and for limited sales to outside users.

Built at a cost of approximately $18 million, the mill is the nation's largest uranium production unit.

This is the story of Kerr-McGee's uranium operations in the Ambrosia Lake area, near Grants, New Mexico.

Kerr-McGee began exploring for uranium in the Ambrosia Lake area in 1955. These efforts were successful and resulted in the discovery of substantial reserves of uranium ore.

The company developed mining operations, and in 1958, constructed a uranium processing mill, the largest of its kind in the United States. The mill produces uranium concentrate (U_3O_8)—commonly known as yellow cake.

URANIUM MINING

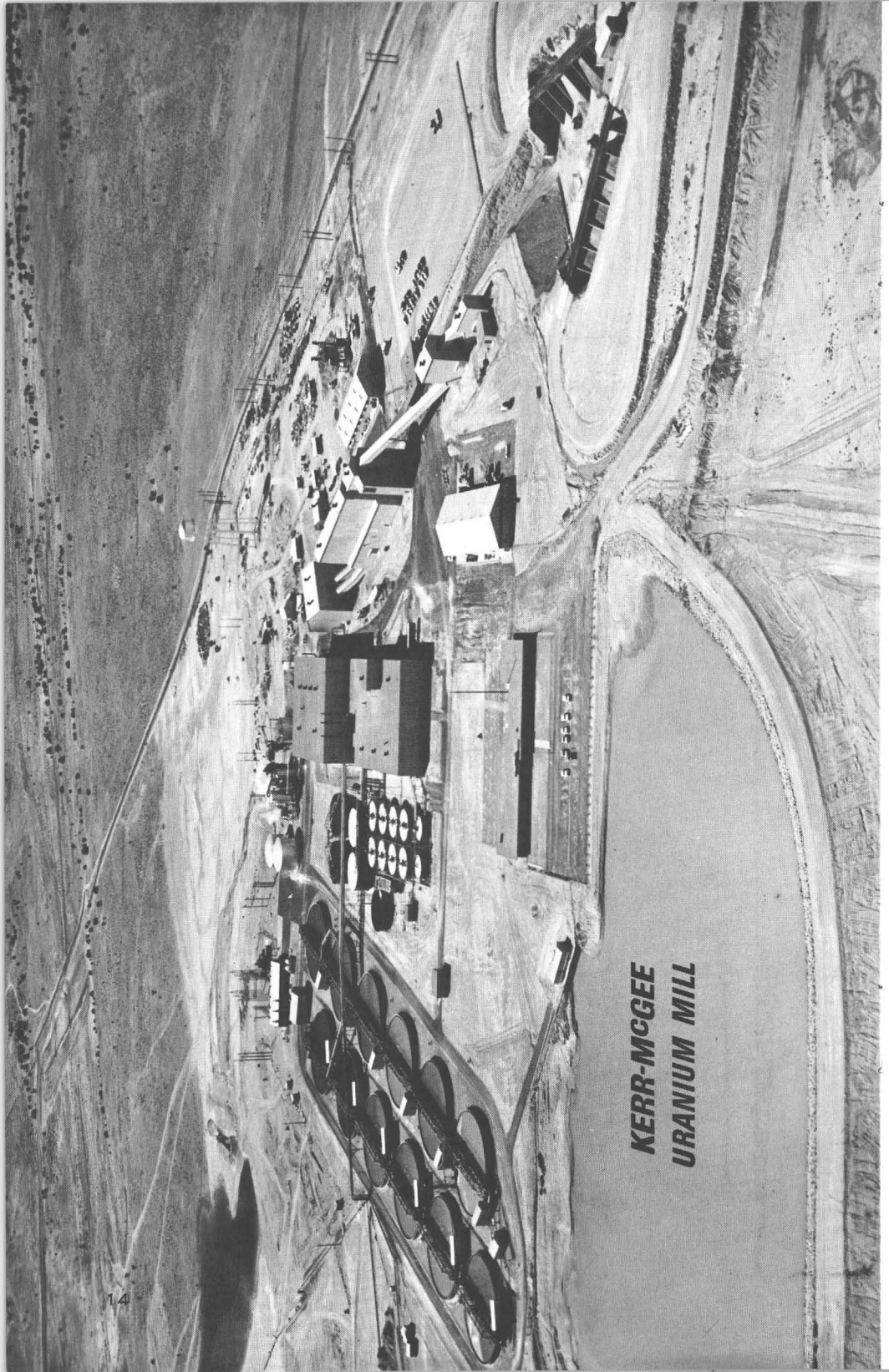
The barren acid-water solution, or "raffinate", free of uranium, leaves the last stage of the solvent extraction circuit and is pumped back into the thickener circuit as a washing solution, or to the tailings disposal pond.

From the solvent extraction circuit, the uranium, now concetrated in the solvent solution, is pumped to the stripping circuit. Here the uranium is stripped from the solvent in a four-stage mixer-settler circuit and again concentrated. The latter is accomplished by advancing one part of stripping solution through 10 parts of solvent solution.

The acid-strip solution leaving the circuit contains approximately 30 times the concentration of uranium as compared to the acid-water solution that was introduced into the solvent extraction circuit.

The solvent leaving the last stage of the acid stripping circuit is free of uranium and ready for re-use in the solvent extraction circuit. The solvent might be referred to as a "selective carrier" of uranium. It picks up uranium in the solvent extraction phase and deposits uranium in the acid stripping solution.

Leaving the stripping circuit, the strip solution, containing concentrated uranium, flows to the precipitation circuit. Here the uranium, which up to this point has been in solution, is caused to precipitate or actually "fall out" of solution. The addition of ammonia, air and heat in the precipitation circuit causes the uranium to become insoluble in the acid-strip solution.



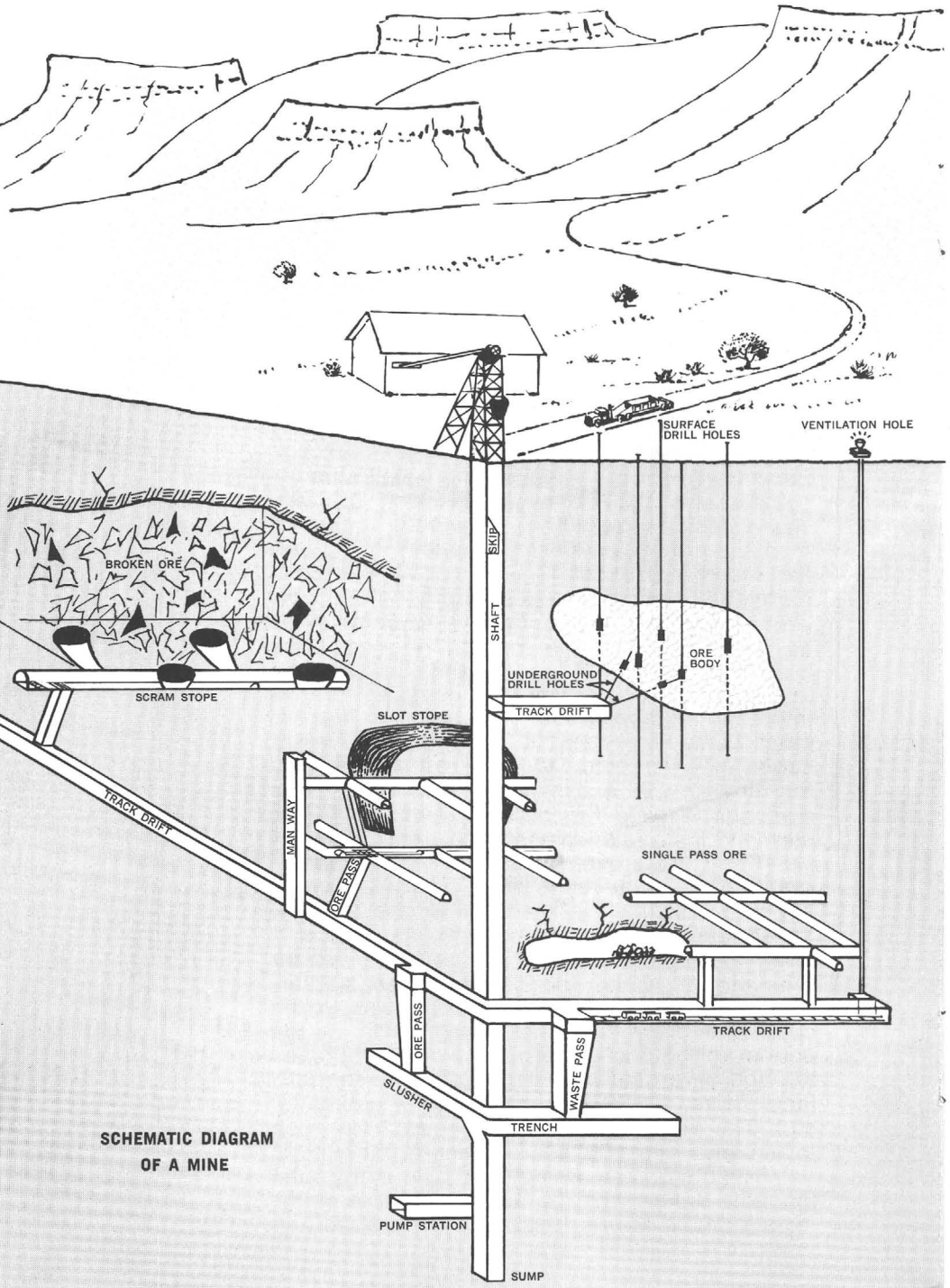
Kerr-McGee Corporation operates eight underground shaft mines in the Ambrosia Lake area of New Mexico. Typical shaft mines are illustrated in the diagramatic sketch on page 4.

The shaft is a vertical hole sunk to ore bearing formations at depths of from 600 to 1400 feet.

Each shaft is equipped with a headframe constructed on the surface. The headframe accommodates the skips which bring ore and waste (rock having little or no value) to the surface and provides a conveyance for moving men and material. The shaft has two equal-size compartments in which ore skips are hung on heavy wire hoist ropes, each from a separate hoist drum. The skip at the loading pocket at the bottom of the shaft, is loaded at the time the skip in the second compartment is dumping its load into a bin on the surface. The shaft also has two other compartments: one in which the power cable, pipelines and ladders are installed; and the other in which a mancage is operated. The mancage is used for lowering and raising the men and materials for operation of the mine.

From the shaft, various levels, or tunnels (trackdrifts) are driven in waste by drilling, blasting and hoisting the material to the surface. These levels are located beneath ore bodies in order to utilize gravity for ore handling and for drainage of ground water from the ore bodies. The ground water flows from the levels to the shaft and down to a collecting sump at the bottom of the shaft where the water is pumped through a vertical pipe in the shaft to the surface. There, the water is collected for use in the mill. The volume of water pumped from each mine varies from 200 to 1,000 gallons per minute.

The ore bodies are outlined by underground longhole drilling and the holes probed to determine location of ore. Raises for ore passes and



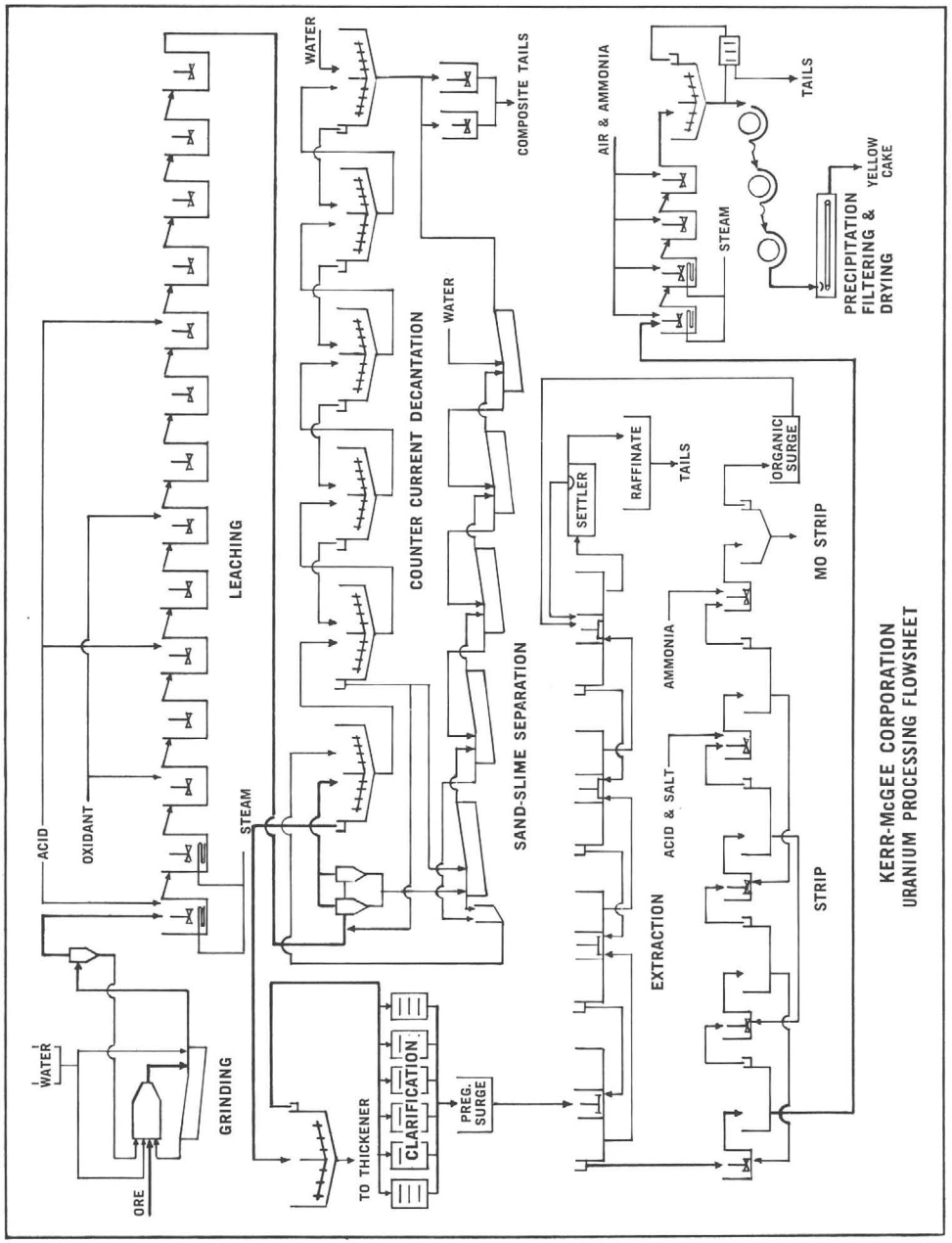
SCHEMATIC DIAGRAM OF A MINE

As the acid-water-uranium solution leaves the #1 thickener, it has advanced through five stages of sand washing and six stages of slime washing. The solution now contains all the uranium that can be economically removed from the ore (90-97 percent). This completes the second stage of ore processing. In summary, the leaching and counter-current decantation processes remove the uranium from the host rock.

As has been previously pointed out, the leaching process removes metals other than uranium from the host rock. Ambrosia Lake ore normally contains trace amounts of vanadium, molybdenum, iron, and various other metals. Therefore, it is necessary to extract the uranium from the acid water solution. In Kerr-McGee's mill this is accomplished by a process known as "solvent extraction."

Before entering the solvent extraction (SX) circuit, the solution is clarified or filtered to assure that no minute solid particles of slime are entrained. As the uranium solution enters one end of the SX circuit, barren solvent solution is introduced at the other end. The two solutions advance counter-current to each other through four stages of mixing and settling.

The solvent extraction, or liquid ion exchange process, performs two basic functions. First it selectively removes the uranium from the acid-water solution leaving the unwanted metals in solution. The concentration is accomplished by advancing solvent through the circuit at one-third the rate of acid-water solution flow. This concentrates the uranium in the solvent three-fold.



manway accesses are then driven vertically from the levels to the ore bodies. The development of the ore is accomplished by various types of openings selected for the best method of ore extraction. The selection of the mining method for each ore body depends on the stability of the ground, the size and shape of the ore body and the cost of extraction.

The ore is drilled, blasted and moved by mechanical slushers to the raises from which it is pulled out of chutes at the bottom of the raises into ore car trains. The trains, powered by electric locomotives on rails, move the ore to the shaft pocket where it is dumped for gravity flow to a slusher trench.

In the slusher trench, the ore is moved with a large slusher hoist and bucket to a loading pocket which is measured to fill one ore skip of 4 to 6 tons capacity. The skip loads are hoisted to the surface for distribution to stockpiles or to the mill.

Waste is handled the same as ore except it is dumped on the waste pile and not processed in the mill. Later, the waste piles are leached to recover small amounts of uranium ore contained in the waste.

Ventilation holes (36" to 72" diameter) are drilled to connect with the underground workings. A large fan is installed at the top of the hole on the surface for exhausting the mine air which enters the shaft. The fresh air passes through the mine workings and exhausts through the ventilation holes in order to maintain a proper atmosphere for men working underground.

All personnel entering the mines wear hard hats with electric lamps, safety glasses, hard-toed boots and other suitable gear necessary for particular working conditions.

URANIUM PROCESSING

metals that are soluble in sulfuric acid are leached, or dissolved. The sodium chlorate oxidizes the ore, which speeds up the leaching process and improves the recovery.

During the leaching process the ore slurry is continuously mixed with the leaching and oxidizing agents for approximately eight hours. At the end of the leaching phase, the ore is pumped into cyclone classifiers for sand-slime separation. This classifier separates the heavier particles (sand) from the lighter particles (slime) by centrifugal force.

The sand is removed from the bottom of the classifiers and the slime from the top. The sand, still in a slurry state, is fed into a five-stage rake classifier circuit, where it is thoroughly washed with acid-water solution. As the sand is washed, the uranium, now in solution, is separated from the individual sand grains. At the end of the rake classifier circuit, the barren sand is pumped to the tailings disposal pond.

From the cyclone classifier the lighter component of the ore slurry (slime) is pumped to the thickener circuit. Here the slimes go through a six-stage washing cycle to remove uranium attached to the microparticles of slime. Barren slime removed from the last thickener is pumped to the tailings disposal pond. The washing of the sand and slime particles, as described above, is collectively referred to as counter-current decantation. This means that a weak acid solution is advanced counter current to the flow of sand and slime in a washing or scrubbing action to displace the higher grade uranium solution that is still attached to the tiny particles.

Leaving the secondary crusher, the crushed ore drops onto another conveyor belt and is carried to the sample tower. In the tower the ore lot passed through a series of sample cutters. The ore is cut until a 200-pound sample, representative of the entire lot, is obtained. Further manual sampling reduces the sample to a six-ounce amount, which is used by chemists to obtain an accurate assay of the uranium oxide content of the original ore lot. The ore then passes to the fine ore storage bins.

The fine ore storage bins serve two basic purposes. First, they provide storage capacity for the ore prior to chemical processing, and second, they provide a facility for blending the ore to the proper grade for plant processing.

Ore leaving the fine ore bins divides into two lines and is fed to the rod mills. Flowing into the rod mills, the ore is mixed with water and ground to minus 28 mesh. This means the ore is reduced to a size that will pass through a screen with 28 openings to the lineal inch.

As the ore leaves the rod mill it is in the form of a mud slurry of approximately 50 percent solids and 50 percent water. Up to this point, the ore has been physically treated; no chemicals have been added. In summary, it has been weighed, sampled for moisture, crushed, sampled for uranium content, blended and ground. The ore is now ready for chemical treatment.

From the rod mills the ore slurry is pumped to the leaching agitators. As the slurry enters the leaching circuit, sulfuric acid and sodium chlorate are added. Uranium and any other

The function of the Kerr-McGee uranium mill is to extract uranium oxide (U_3O_8) concentrate, commonly called yellowcake, from uranium-bearing ores.

Trucks haul the grayish sandstone ore to the mill from company-owned mines in the Ambrosia Lake area.

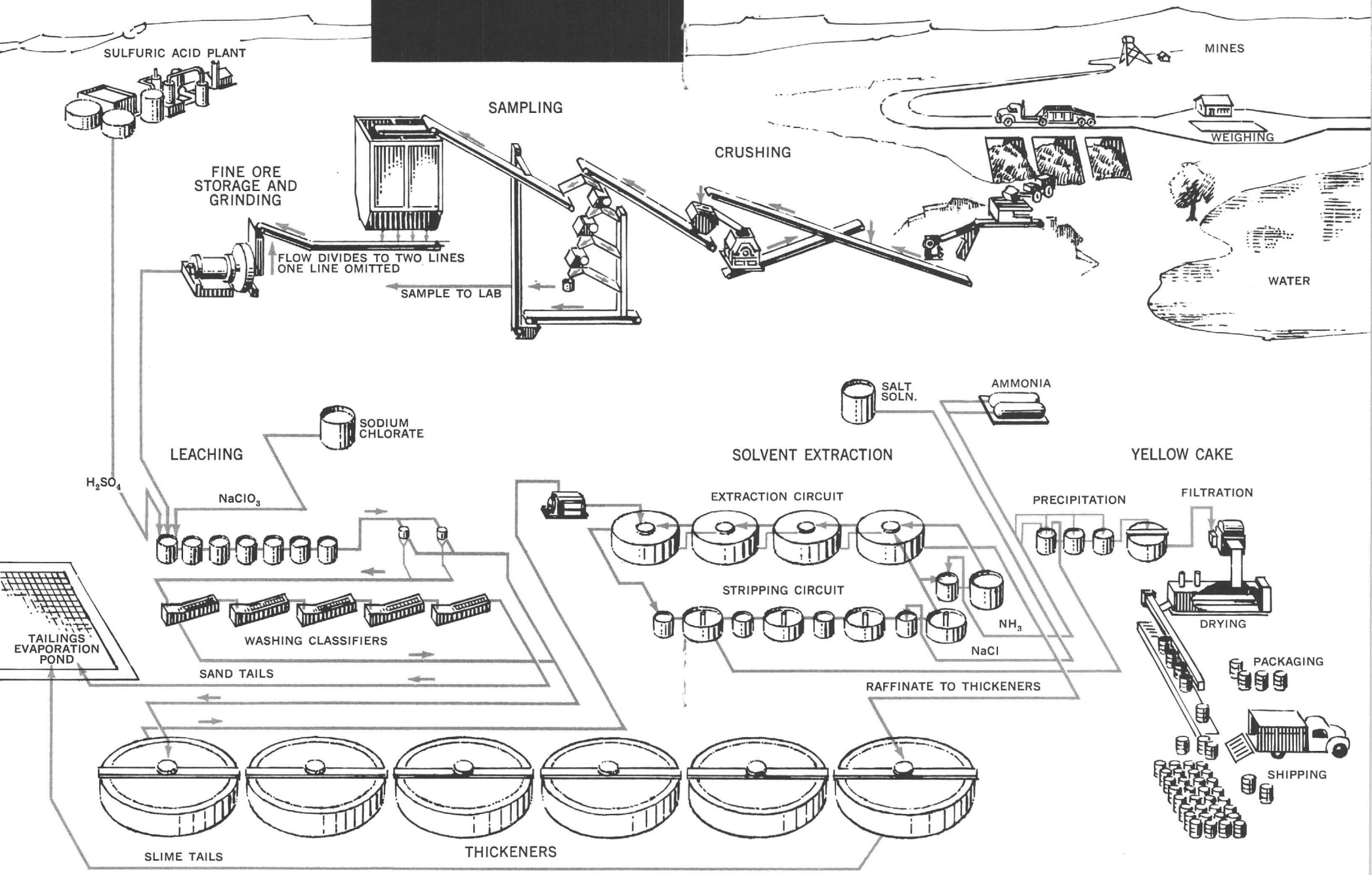
The trucks drive up on large scales and the ore is weighed. The trucks move from the scales to the moisture sample station, where ore samples are taken and weighed. The samples are then dried and weighed again to determine the moisture content.

Accurate computation of the moisture content is highly important, because the amount of ore fed to the mill is always figured in dry-ton equivalents.

From the moisture station the trucks roll on to the ore receiving pit where the ore is dumped. The ore receiving pit contains 16 ore pockets, each of which will accommodate 1,000 tons of ore.

Large front end loaders move the ore in approximately 2,000-ton lots (ore is processed in approximately 2,000-ton lots at a time) from the pockets to a "grizzly" or grill where the material drops into the primary crusher where the ore is crushed into chunks less than four inches in diameter. A 36-inch conveyor belt speeds the ore from the primary crusher to the secondary crusher, which further reduces the ore into less than one-inch diameter chunks.

KERR-McGEE URANIUM MILL



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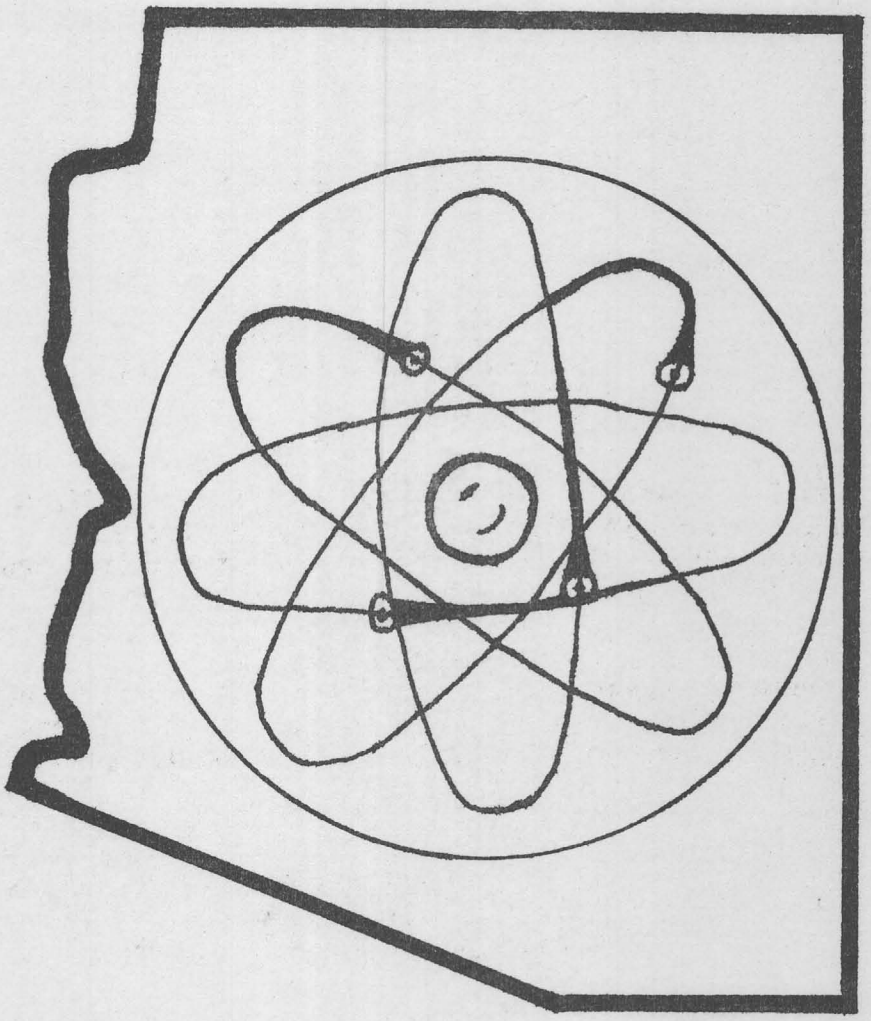
URANIUM
A PROSPECTOR'S GUIDE

SPECIAL REPORT NO. 1



BY

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ARIZONA DEPARTMENT OF MINERAL RESOURCES

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URANIUM

A PROSPECTOR'S GUIDE

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1978
Revised April 1979

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URANIUM

A PROSPECTOR'S GUIDE

Arizona Department of Mineral Resources
Special Report Number 1

INTRODUCTION

Uranium - A Prospector's Guide has been published by the Arizona Department of Mineral Resources as a guide to the independent prospector searching for occurrences of uranium. The report discusses uranium prospecting with particular emphasis on the use of radiation detectors (Geiger-Müller and Scintillation Counters) and the ultraviolet lamp. Additional chapters present brief descriptions of the geology and mineralogy of uranium. A number of recommendations for prospecting are given, in the chapter on that subject. The report concludes with a chapter on sources of information and a bibliography.

Voluminous books, guides, reports, maps, etc., have been written on uranium, its mineralogy, geology, occurrences, mining, processing, and use. For maps and descriptions of occurrences, the details of geology, mining laws and regulations, and marketing, the reader is referred to the final chapter on literature and to the Arizona Department of Mineral Resources.

The authors wish to acknowledge a number of publications which were invaluable in the preparation of this report. Coal, Oil, Natural Gas, Helium and Uranium in Arizona by H. Wesley Peirce, Stanton B. Keith and Jan Carol Wilt (Arizona Bureau of Geology and Mineral Technology, 1970) was of great assistance in the preparation of the chapter on geologic environments and Arizona's uranium position. A great amount of information for the preparation of the chapter on radiation detection was taken from Robert J. Wright's Prospecting With A Counter (U.S., AEC 1954). Data and ideas for the chapter on fluorescence were provided by Sterling Gleason's Ultraviolet Guide To Minerals, (U.V. Products, 1960). Dr. Richard M. Pearl's Handbook for Prospectors, (McGraw-Hill, 1973) was extremely valuable in preparation of the chapter on prospecting and for other ideas presented in this report.

Uranium

Uranium is a metallic element with the chemical symbol U, atomic number 92, and atomic weight 238.07. It is the last and heaviest of the naturally occurring elements in the Periodic Table. Natural uranium is a mixture of three isotopes, i.e., elements having the same atomic number but differing in atomic weights. These isotopes of uranium are U^{238} (99.285 percent), U^{235} (0.71 percent), and U^{234} (0.005 percent). These percentages may vary slightly from one geographic source to another. U^{235} is the only naturally fissionable isotope or nuclide of uranium; but under the bombardment by neutrons, the more common isotope, U^{238}, produces plutonium 239 (Pu^{239}) which is another fissionable material. U^{234} is not fissionable and of no importance in atomic energy.

U238 and U235 are called radioactive because they break down spontaneously at a constant rate into isotopes of other elements by the emission of charged particles from the nuclei of their atoms. In the breakdown through different series of isotopes or daughter products they each end up eventually as stable lead isotopes. The rate of decay is measured in half-lives; 4.51×10^9 (4,510,000,000) years for U^{238} and 7.1×10^8 (710,000,000) years for U^{235}. Half-life is the period of time in which one half of a radioactive substance will radioactively decay.

The use of uranium as a source of energy, first for military purposes and more recently for supplying sustained power, has evolved only within the past forty years. This energy, called nuclear or atomic energy, can be derived from the fission of uranium in which the atomic nucleus of fissionable uranium is hit by a free neutron and then splits violently into two different elements and yields a large amount of energy in the form of heat. In this fission only about 0.1 percent of the mass is converted to energy. Theoretically one gram of fissionable uranium could furnish as much heat as three tons of good coal and one pound could supply ten million kilowatt-hours of electrical energy. Nuclear fission releases additional neutrons that can bombard other uranium nuclei and thus set up a continuing process called a chain reaction. The use of neutron-absorbing or moderating materials can control the reaction at the desired rate and the regulated energy released can be used for producing heat, power, propulsion, and additional useful fissionable or radioactive materials or isotopes.

Uranium was discovered and named in 1789 and isolated in 1841. Becquerel, in 1896, first noted the radioactive character of uranium. Early experiments with uranium and radioactivity excited little public interest. Uranium salts were used in limited amounts as coloring agents in ceramics and glass and in specialized photography and luminous paint. The total demand for uranium ore up to the early 1940's was never more than a few hundred tons of very high grade material per year.

World War II and the use of uranium in atomic weapons diverted nuclear energy research almost exclusively into military channels. Nevertheless, the successful demonstration of a controlled chain reaction by Fermi and his associates in Chicago in December, 1942, opened the door to the eventual use of uranium as a commercial source of energy for civilian purposes.

ECONOMIC URANIUM MINERALS

Minerals

Minerals are the building blocks of which the lithosphere (solid rock portion) of the earth is constructed. Over 2,500 such substances have been recognized and described by trained mineralogists. Of these only a few hundred are of commercial consequence in our metallic, non-metallic and energy industries. Around 200 uranium and thorium mineral species have been recognized. However, the uranium prospector needs to only recognize less than ten of these to be effective. The recognition and identification of all minerals is based upon certain fundamental concepts including:

1. Minerals are naturally occurring.
2. Minerals are inorganic chemical compounds.
3. Minerals are homogeneous (all parts of a given mineral are alike).
4. Each mineral possesses rather definite physical properties such as, hardness, color, luster, etc.
5. The chemical composition is sufficiently constant that simple formulas may be written for it.

A mineral's physical properties are the prospector's most useful keys in their recognition and identification. These properties are:

1. Radioactivity
2. Fluorescence
3. Luster
4. Habit
5. Specific gravity
6. Color
7. Cleavage and fracture
8. Hardness.

A discussion of these physical properties as they pertain to the recognition of uranium minerals of interest to the prospector follows.

Radioactivity

Certain minerals, including all those containing the elements uranium and thorium and some others, spontaneously emit small particles of matter from their atoms in a process called radioactivity. Special techniques are required for recognition of this property, and this most important aspect of uranium minerals and uranium prospecting will be discussed more thoroughly later.

Color

Most of the more common uranium minerals have a distinctive color and visual examination alone is a significant aid in recognizing a number of minerals. The color of a mineral is largely the result of its chemical composition. The secondary (more about that term later) commercial uranium minerals often exhibit bright hues of yellows and greens while the primary uranium minerals range from dark greenish to black.

Luster

Luster is the appearance of a freshly broken surface of a mineral in reflected light. Some of the most common distinctions include:

1. Metallic - surface reflection like a metal.
2. Glassy - looks like the surface of bright glass.
3. Greasy - reflection similar to an oily surface.
4. Silky - appearance of silk in light.
5. Resinous - like resin, almost waxy.
6. Pearly - like mother-of-pearl.
7. Dull - reflects little light (for example, clay)
8. Earthy - no noticeable reflection of light.
9. Pitchy - like pitch or tar.

The uranium minerals have, for the most part, earthy, pearly, glassy, dull or pitchy lusters.

Habit

The habit of a mineral refers to the characteristic form assumed by a mineral as found in the field including its general shape and irregularities of growth. The habit of minerals may be as crystals (definite shapes such as cubes, pryamids, prisms, etc.), rounded grains, radiating groups, nodules, banded, massive, etc. The common habits for the uranium minerals are plates or scales, earthy masses and coatings.

Specific Gravity

Specific Gravity or "heft" is the comparative weight of a volume of a mineral to the weight of an equal volume of water. The specific gravity of water is arbitrarily set at "one". If a mineral has a specific gravity of 3.5, a given volume of the mineral weighs 3.5 times the same volume of water. The specific gravity of common rock is about 2.6. Any mineral or rock of significantly greater heft (heavier than the same sized piece of common rock) should arouse any prospector's (uranium or otherwise) interest. Specific gravity values for pure uranium minerals range from 3 to 10. However, since most uranium minerals occur mixed with other minerals or as very thin coatings on average heft rocks, valuable uranium ores may not necessarily have significantly high specific gravities.

Fluorescence

Fluorescence is the property of a substance to emit visible light in a darkened space when acted upon by ultra-violet light. Special mineral lights or black lights are used for this purpose. Fluorescence has been detected in some specimens of about 600 different mineral species. A few nearly always exhibit fluorescence, many only rarely. Five of the important uranium minerals are either always or occasionally fluorescent. In addition there are about 50 rare or trace uranium minerals, the so-called "uranium ochers"or "color halos" that are sometimes fluorescent and may provide a clue to the presence of economic uranium minerals. Fluorescence will also be discussed further.

Cleavage and Fracture

The orderly arrangement of the elements (such as uranium, thorium, oxygen, etc.) into minerals builds a strong atomic structure in certain directions and weak structures in others. When a mineral breaks with ease along the weak directions a smooth surface is usually produced which readily reflects light. This property of ease of breaking into plain-like forms is called cleavage. It may be in one or more directions. If the mineral breaks unevenly or with a curved, shell-like (conchoidal) surface, this property is known as fracture. Some uranium minerals have three directions of cleavage, some two, some one and others show no cleavage but conchoidal to uneven fracture instead.

Hardness

The hardness of a mineral is an expression of its resistance to abrasion or to scratching. It ranges on an arbitrary scale from "one" (soft like talc) to "ten" (hardest substance known, diamond). A mineral with a hardness of "one" will mark the flesh of the hand or a piece of paper. The fingernail is about "two"; a copper penny, "three"; a steel knife blade, "five"; and window glass between "five" and "six" (5.5) in hardness. The mineral, quartz, has a hardness of "seven" and there are only a few minerals which are harder. If the minerals occur as small aggregates, coatings, or are powdery in nature, the hardness determinations will be difficult, inconclusive and of little use. Otherwise it is a simple matter to relate scratching ability to the common articles named above. A mineral which may scratch a fingernail but will be scratched by a penny is said to have a hardness of between "two" and "three" or simply 2.5, etc.

Most of the uranium minerals in pure crystalline or massive form have a hardness of less than "six"; the brighter-colored oxides of uranium range from "two" to "three".

Uranium Minerals

The uranium minerals are divided by geologists into two general classes: primary and secondary. Most primary minerals are those that have been formed by heated gases and solutions coming up from deep within the earth. Secondary minerals have been formed by alteration of the primary minerals as a result of the weathering action of ground waters or other natural processes. Primary uranium minerals are readily altered to the secondary varieties as a result of this chemical action.

Primary uranium minerals usually occur in vein deposits (tabular bodies), pegmatites (coarse-grained igneous dike rocks) and mixed with secondary uranium minerals in Colorado Plateau sedimentary deposits. They are generally dark-brown to black, have a high specific gravity, and usually a dull, pitchy luster.

A brief description follows for each of the common ore-making uranium minerals.

Primary Uranium Minerals

Uraninite, including its massive impure variety, pitchblende, is the most important primary (sometimes secondary) uranium mineral. Uraninite is found in isolated crystals and masses in veins and dikes. It is also found as stringers, lenses and blebs filling cavities in rocks and occasionally is disseminated as dustlike grains similar to carbon dust. Uraninite is essentially uranium oxide with a variable uranium content of 46 to 88 percent. Pitchblende often occurs in rounded, irregular masses, and then breaks with a curved (concoidal) surface as does glass. Pitchblende is heavier than steel, about as hard, and is grayish or greenish black.

Coffinite is a significant uranium mineral in many of the Colorado Plateau sandstone uranium deposits. When found in such deposits it is typically associated with pitchblende. Further its physical characteristics are very similar to those of pitchblende (See Table 1).

The other major, so-called primary uranium minerals, brannerite and davidite are rare enough as to not need consideration here.

Secondary Uranium Minerals

The secondary uranium minerals are characterized by their bright colors, including yellow, orange, and green. They usually occur as earthy or powdery masses, as groups of very small crystals, or as flat plates. The secondary minerals are present in almost any type of rock, and may or may not be found with primary minerals. A few of the more common secondary minerals are carnotite, tyuyamunite, autunite and torbernite.

Carnotite is generally considered the most important secondary uranium mineral. Carnotite is a hydrated potassium uranium vanadate. It is bright yellow in color with an earthy appearance and an indeterminate hardness. As it is often very difficult to distinguish between carnotite and a great variety of other less common yellow uranium minerals, carnotite is a useful descriptive name for the group.

Tyuyamunite resembles carnotite but is more greenish-yellow and may fluoresce yellow to a weak apple green.

Autunite is a bright lemon-yellow material. It is soft and occurs in small flat and translucent crystals. It always fluoresces a bright yellow or apple green when exposed to ultraviolet light.

Tobernite and meta-torbernite are bright green minerals. They are soft and occur in flat transparent crystals.

TABLE 1

CHARACTERISTICS OF COMMON ECONOMIC URANIUM MINERALS

NAME & CHEMICAL COMPOSITION	COLOR	LUSTER	HABIT	FLUORES-CENCE	HARDNESS & (SPECIFIC GRAVITY)	CLEAVAGE (FRACTURE)
PITCHBLENDE (Uranium Oxide)	Grayish black; Greenish black	Pitchlike, dull, earthy or glassy	Massive; rounded surface; banded	None	5 to 6 (6 to 9)	(Conchoidal or Uneven)
URANINITE (Uranium Oxide)	Grayish-black; Greenish-black; Brownish-black	Pitchlike; dull; or glassy	Small cube-like crystals; massive	None	5 to 6 (8 to 10)	(Conchoidal or Uneven)
COFFINITE (Hydrated silicate of uranium)	Black, pale to dark-brown	Dull to adamantine	Fine aggregates; disseminations; small bodrgoidal	None	5 to 6 (5)	(Conchoidal or Uneven)
SAMARSKITE (Complex mineral containing uranium and rare earths)	Liver-brown	Glassy	Massive; coarse crystals; radiating crystals	None	5 to 6 (4 to 6)	(Conchoidal or Uneven)
CARNOTITE (Potassium uranium vanadate)	Canary-yellow	Earthy; pearly	Earthy masses; thin coatings	Yellow Short-wave	2 to 3 (4 to 5)	One Direction
TYUYAMUNITE (Calcium uranium vanadate)	Greenish-yellow	Earthy; pearly	As scales; thin coatings; earthy	None; or weak apple green	2 to 3 (3 to 4)	Three Directions
AUTUNITE (Calcium uranium phosphate)	Lemon-yellow; sulfur-yellow; apple-green	Pearly	Thin plates; micaceous; earthy	Brilliant yellow; or apple green	2 to 3 (3)	One Direction

Table 1 Continued
Common Economic Uranium Minerals

NAME & CHEMICAL COMPOSITION	COLOR	LUSTER	HABIT	FLUORES-CENCE	HARDNESS & (SPECIFIC GRAVITY)	CLEAVAGE (FRACTURE)
URANOPHANE (Calcium uranium silicate)	Lemon-yellow; pale greenish, straw or orange yellow	Pearly; greasy	Radiating aggregates; fibrous; or massive	None; or faint green	2 to 3 (4)	Two Directions
GUMMITE (Complex hydrated oxide of lead and uranium)	Yellow to deep orange or brown; of variable color	Dull; waxy; greasy; glassy	Massive; as crusts	None	2 to 3 (4 to 6)	(Conchoidal or Uneven)
TORBERNITE And METATORBERNITE (Copper uranium phosphate)	Bright green; Emerald-green; Apple-green	Pearly	Mica-like square crystals; soft masses	None; or faint green	(3 to 4)	Two Directions
MONAZITE (Cerium and rare earth Phosphate)	Golden-yellow yellowish; reddish or greenish-brown	Resinous	Flattened or tabular crystals	None	5 to 6 (4 to 5)	Good (Conchoidal or Uneven)

RADIATION DETECTION

Name your locality and the chances are favorable that uranium minerals may be found. But, that's no promise they'll be in commercial amounts or minerals from which the uranium can be feasibly recovered. Few other elements are known to occur in as many types of geological settings as uranium. It is therefore reasonable that many deposits may have been overlooked. One of the most active uranium prospecting and exploration regions in Arizona; at present, the Bill Williams River - Date Creek Basin area of northern Yuma and southwestern Yavapai Counties was of little interest 25 years ago.

Before discussing prospecting and field procedures, two pieces of equipment should be discussed. They are the radiation counter and the ultraviolet light. By far the most important of the two for uranium prospecting is the radiation counter. Although not an absolute necessity, radiation detection instruments are so valuable in radioactive-mineral prospecting that the subject is scarcely worth discussing without them.

Dr. Richard Pearl in his Handbook for Prospectors (5th edition, McGraw-Hill Book Company, 1973) introduces the subject of prospecting with a radiation counter by stating three basic principles:

1. Although it is probably true that any child can operate a Geiger counter, it takes a certain amount of experience and judgment to use it effectively.

2. Although the Geiger counter (and its more sensitive relative, the scintillation counter) is a modern effective electronic device, the commercial value of radioactive ores is determined by chemical analysis. The counters, therefore, merely indicate the presence of a reaction, they do not provide actual evaluation of uranium content without additional data.

3. These instruments are detectors of radioactivity in general, yet only uranium, and to a much lesser extent thorium, have any significant value. In addition to uranium and thorium, potassium as well as many other elements are sometimes radioactive, and the surface of the earth is continually receiving cosmic radiation, all of which influence the readings on radiation counters.

Although these three points may be discouraging, remember uranium prospecting can be profitable, and it can be easier than prospecting for most other types of minerals. The instruments can do most of the work for you, provided you do the thinking! The most successful prospecting ventures are those which are well thought out using sound scientific principles and carried out by thinking individuals.

Atomic Radiation

To effectively use a Geiger or scintillation counter (they will both be described shortly) it is desirable to understand something about radioactivity. This is the spontaneous automatic breakdown (disintegration, decay) of chemical elements as they change into other lighter elements. Every natural element has at

least one isotope that is radioactive, and all the man-made elements are radioactive. For prospecting purposes only uranium, thorium and sometimes potassium are of concern. Both uranium and thorium decay finally to lead, which is the stable (nonradioactive) end of the decay series. During the transformations that take place, heat is generated, helium gas is given off, subatomic particles are emitted, electromagnetic radiation is emitted, and a number of intermediate "daughter elements" or "daughter products" are formed, which in turn break down radioactively.

The radiation that is produced by this natural process cannot be hastened or delayed by pressure, heat, or chemical means and is constant during the passage of time. It consists of alpha and beta particles, and gamma rays. Alpha particles are positively charged particles of weak penetrating power, (essentially a helium nucleus); beta particles are negatively charged particles of somewhat greater penetrating power; essentially an electron and gamma rays are uncharged electromagnetic radiation, being true rays like X-rays, light rays, etc. The Geiger and scintillation counters record chiefly gamma rays, and some prospecting devices measure beta radiation.

You should be aware that, although some important uranium minerals are luminescent and will glow in ultraviolet light, this effect is not caused by radioactivity, which is invisible. Neither are there any magnetic properties that might influence a watch or compass. The radiation is soundless.

Regardless of their apparent variety, radiation counters for use in prospecting belong to two fundamental types. These are the Geiger counter, and the scintillation counter. Because of its higher sensitivity, the scintillation counter is probably as popular as the Geiger counter in spite of its higher cost. Other types of radiation detectors such as the ionization chamber, spinthariscope, radioscope and electroscope have been used in early day uranium prospecting, but were not well adapted or popular and are not discussed here.

Geiger Counter

The Geiger-Müller counter was developed as a sensitive device for measurements of radioactivity in the laboratory. The first field instruments were clumsy, but the modern prospecting counter is a compact, rugged instrument. Specialized counters have been designed for a variety of specific jobs, such as prospecting from the air, examining bore-holes, and radiometrically probing ore shipments.

The heart of the Geiger counter is the Geiger tube. It is made of metalized glass or metal and may be from a few inches to several feet in length.

In some counters, the Geiger tube is contained within the counter case, whereas in others the tube is separate, and connected to the case by a conducting cable. The tube is filled with one or more gases, such as helium, argon, or krypton, and in operation a positive charge of about 1,000 volts is applied between the glass or metal shell and a center wire.

A radioactive element such as uranium emits either alpha or beta particles and may emit gamma rays as well. When a Geiger counter is placed near such an element the tube is struck by the radioactive emissions. Alpha particles are

stopped by the tube wall and cannot affect the tube. Beta particles have greater penetrating power and some of these can enter the tube and be recorded. Gamma rays, which are still more penetrating, can penetrate the wall, but most pass completely through the tube with no effect. A few gamma rays - about one half of one percent - enter the tube and collide with a molecule of the enclosed gas to produce electrons. The negative electrons thus produced are attracted toward the positively charged center wire and produce a negative electrical pulse as they strike the wire.

In addition to the tube, a Geiger counter contains a battery operated power supply, an amplifier, and one or more indicators. The indicator may be a neon light, or a meter, which gives a visible indication of radioactivity, or a headset, or speaker which gives an audible indication. The light flickers and the earphone clicks each time the Geiger tube discharges. The meter gives an average measurement of radioactivity.

Scintillation Counter

It was noted above that a Geiger detects gamma and occasionally beta rays by the ionizing effect they have upon gases contained within the Geiger tube. A scintillation counter, like the Geiger counter, also measures gamma and occasional beta rays, but it depends upon another property: the ability of gamma (and beta) rays to produce tiny momentary flecks of light (scintillations) in crystals of certain compounds such as sodium iodide and potassium iodide.

The chief advantage of a scintillation counter is that it responds to a large proportion of the gamma rays that hit the crystal. Depending on the type and size of the crystal, scintillations are produced by 50 percent or more of the gamma rays that strike the crystal. In contrast, most Geiger tubes are discharged, as stated before, by less than 0.5 percent of the gamma rays which penetrate them. This means that the crystal counter is more sensitive.

The arrangement of component parts is similar in both types of counters. In place of the Geiger tube, a scintillation counter employs a small crystal, usually made of sodium iodide, attached to the end of a light-sensitive photomultiplier tube. Both crystal and photomultiplier tube are sealed in a light-tight unit so that the instrument cannot be triggered by sunlight. The tube "sees" the scintillations produced in the crystal and transmits them as electrical pulses. These are amplified and passed through an averaging circuit to a recording meter.

Using Radiation Detectors

A few general suggestions about the use of a Geiger or scintillation counter should be made:

1. Because of the high voltage necessary to charge the Geiger tube, or operate the photomultiplier tube, it is important that the equipment be kept dry, otherwise the counter may short out. Some instruments are especially sealed by the manufacturer against moisture, but unless this has been done the counter should not be used in a humid environment, such as a wet mine.

2. The counter should be protected from contamination by radioactive clothing, mine or mill dust or ore specimens.

3. If individual clicks cannot be distinguished or the needle swings to the top of the indicating dial, the radioactive field may be so intense that the counter might be damaged. Use a less sensitive counter setting or move away from the source of radioactivity.

4. The counter should of course be turned off when not in use in order to conserve the batteries.

5. To obtain an accurate reading, keep the counter away from any watch, compass, or other instrument which has a luminous dial. The luminous paint contains a radioactive radium compound.

A Geiger counter is adequate for most geologic and mining problems. However, the higher sensitivity of a scintillation (crystal) counter makes it especially useful for measuring low levels of radioactivity, for making radioactivity surveys, and for prospecting from the air.

Many kinds of counters are manufactured for field use and before purchasing one, the user should determine which type most nearly fits his needs and pocketbook.

Gamma Radiation

Since the discovery of radioactivity in 1896, researchers have attempted to determine the nature of the emissions produced. In the course of this work many types of radiations have been discovered: alpha particles, beta particles, gamma rays, protons, positrons, neutrons, mesons, neutrinos. Of these, gamma rays are of most importance in the present discussion because field counters are mainly gamma ray detectors. Some Geiger counters have a metal sleeve which can be moved to expose the Geiger tube directly to radiation, but only in this way can a few of the many other particles be detected.

Gamma rays are like X-rays. They:

1. Travel in straight lines at the speed of light.
2. Produce scintillations in certain crystals.
3. Have neither mass nor charge.
4. Blacken photographic film.
5. Penetrate matter.
6. Ionize gases.

Like X-rays, gamma rays can penetrate matter, but the gamma rays produced by uranium minerals have only slight penetration due to their relatively low-energy level. The ease with which gamma rays are absorbed by any material depends on its density. The gamma rays from uranium are stopped by approximately:

3 inches of lead
1 foot of rock
2½ feet of water
Several hundred feet of air.

Since the outer foot of a rock mass absorbs almost all gamma radiation beneath it, a counter cannot detect gamma rays which come from a source deeper than one foot. Once the rays escape from the rock, however, they can travel for some distance through air. In other words, a counter measures only the gamma rays from the outer one foot rock shell and it cannot detect radioactive ores deep within a rock mass. This is a very important limitation on the usefulness of a counter.

To understand the uses and limitations of counters, it is necessary to know a few facts about uranium and its many radioactive daughter products.

Several elements, as mentioned earlier, are naturally unstable and these undergo spontaneous radioactive decay.

Natural uranium contained in ore is made up of essentially two kinds of uranium atoms (isotopes, really) - one with atomic weight of 238 and the other with atomic weight of 235. Uranium - 238 is much more abundant than uranium - 235, by a ratio of 140 to 1. Because of its greater abundance, uranium - 238 is largely responsible for the radioactivity of uranium ore.

When uranium - 238 disintegrates, it forms thorium - 234. This, too, is radioactive and decays to form protactinium - 234, also a radioactive element. Other radioactive elements are formed by this progressive disintegration until finally an inactive element, lead, is formed. Thus, uranium - 238 is the parent element of a long series of radioactive elements. Each is formed by radioactive decay and each yields another radioactive element. The series begins with uranium - 238 and includes 13 radioactive daughter elements, one of which - radon - is a gas. The series ends with lead, which is inactive and undergoes no further decay.

The radioactive decay series for uranium 238 is: Uranium - 238; Thorium - 234; Protactinium - 234; Uranium - 234; Thorium - 230; Radium - 226; Radon - 222; Polonium - 218; Lead - 214 (radioactive lead); Bismuth - 214; Polonium - 214; Lead - 210; Bismuth - 210; Polonium - 210; and Lead - 206, which is stable. (See Table 2.)

Each element emits either an alpha or a beta particle, and in addition, five of the elements are gamma emitters. These five are thorium - 234, protactinium - 234, radium - 216, bismuth - 214, and lead 210. Bismuth 214 and protactinium 234 are the strongest gamma emitters.

It is important to note that uranium itself does not give off gamma or beta rays. Therefore, the Geiger counter, which is primarily sensitive to gamma rays, cannot detect uranium directly. Instead, the counter measures the radiations of the five gamma ray producers, particularly the strong emitters Bismuth - 214 and protactinium. Only when the gamma ray emitters are present in amounts proportional to the amount of uranium can the counter give an accurate measure of the uranium present.

Radioactive Equilibrium

This is a fact of prime importance, since it is a limitation on the accuracy of any uranium analysis made by measuring radioactivity.

Under what conditions, then, are the gamma ray emitters present in normal

Table 2 -- The Uranium Decay Series

Element	Radiometric Designation	Half Life	Radiations (mev.) Alpha	Beta	Gamma
Uranium-238	UI	4,510,000,000 years	4.21		
Thorium-234	UX_1	24.1 days		0.18	0.09
Protactinium-234	UX_2	1.1 minute		2.32	0.80
Uranium-234	UII	269,000 years	4.75		
Thorium-230	Ionium (Io)	82,200 years	4.66		
Radium-226	Radium (Ra)	1,600 years	4.79		0.19
Radon-222	Radon (Rd)	3.8 days	5.49		
Polonium-218	Radium A (RaA)	3.1 minutes	5.99		
Lead-214	Radium B (RaB)	26.8 minutes		0.65	
Bismuth-214	Radium C (RaC)	19.7 minutes		3.15	1.8
Polonium-214	Radium C'(RaC')	0.0002 second	7.68		
Lead-210	Radium D (RaD)	22.2 years		0.025	0.047
Bismuth-210	Radium E (RaE)	5.0 days		1.17	
Polonium-210	Radium F (RaF)	139 days	5.30		
Lead-206	Radium G (RaG)	Stable			

amounts? They are present in normal amounts if the material tested is in radioactive equilibrium.

What is meant by radioactive equilibrium? When uranium is freshly purified and isolated from its radioactive daughter elements, it immediately starts to decay to form its daughter elements. As these progressively decay all the elements in the decay series gradually accumulate. Finally, after about 1 million years, each element is present in such amount that it decays at the same rate as it is produced, and thereafter no further change takes place in the proportion of any daughter element. The series is then in radioactive equilibrium. When uranium ore is in equilibrium, a fixed proportion of each daughter element is present, whether the ore contains 0.1 percent uranium or 50 percent uranium. At equilibrium each gamma emitter is present in its normal amount and the radioactivity measured by a counter is dependent on the amount of uranium present; hence, a counter reading can provide a reliable indication of the uranium contained in the ore.

When is a uranium sample in equilibrium?

Of first importance is the fact that about 1 million years are required for newly purified uranium to reach equilibrium with its daughter products. All the uranium now contained in rocks was assumed present when the earth was formed. Since the earth is estimated to be 4,500 million years old, all uranium in the earth is also assumed to be of this same age. It might then be expected that uranium everywhere should be in equilibrium. This would be the case if it were not for the fact that some uranium-bearing materials have undergone chemical or physical change which has separated the uranium from its daughter elements. If this change took place within the past 1 million years, insufficient time has elapsed for the separated uranium to establish equilibrium again.

Lack of equilibrium, then, results from the separation of uranium from its daughter elements within the last 1 million years. In nature this can result from (1) attack by solutions (such as ground water) and (2) the loss of the gaseous daughter element radon. The first of these is important in many geologic problems, but the second is important only under special conditions.

Non-equilibrium due to attack by solutions is a common result of the oxidation and weathering of outcropping uranium deposits, especially deposits which contain pitchblende and sulphide minerals (such as pyrite, chalcocite, and chalcopyrite). Ores of this type are found in many places throughout the Southwest. Oxidation of pitchblende-sulphide ore forms acidic ground water due to the formation of sulphuric acid by the oxidation of the sulphide minerals. Uranium is soluble in acid waters and tends to be removed in solution, but radium is much less soluble and its compounds tend to remain behind in the leached outcrop. Therefore, the outcrop may be radioactive due to the presence of the gamma-emitting elements Bismuth - 214 and Lead - 210, even though much of the uranium has been lost in solution. As a result, a sample taken from the outcrop may give a high counter reading, but a chemical analysis proves that the uranium content is low.

In places secondary uranium minerals - such as autunite, torbernite, and schroeckingerite - are deposited by ground water. Most such deposits are out of equilibrium. The equilibrium conditions usually vary widely from sample to sample and therefore counter readings are apt to be quite unreliable. Lack of equilibrium in these secondary minerals results from the fact that the minerals

were deposited less than one million years ago. Hence, gamma-emitting daughter elements have not yet accumulated in their equilibrium amounts, and more uranium may be present than is suggested by the counter readings.

Movement of radon - 222, the second cause of non-equilibrium, is much less important than the effect of solution. Radon is one of the daughter elements of uranium. It is a heavy gas with half life of 3.8 days. Being a gas, radon can move by gaseous diffusion. Within rocks it normally diffuses only very short distances because of its comparatively short half life; after 5 half lives (approximately 20 days) radon is almost completely disintegrated to polonium - 218, a solid element, and further gaseous diffusion is stopped.

The effects of radon - 222 are most noticeable in confined spaces such as mine workings, tunnels, drill holes, etc.

In the use of a Geiger or scintillation counter a number of practical problems need to be brought out. They are, in addition to the equilibrium and radon gas effects already discussed: (1) background effect, (2) absorption effect, (3) cover effect, (4) cosmic effect, (5) mass effect, (6) natural radioactivity and (7) underground effect.

Background Effect

Most things are slightly radioactive. All rocks carry, on the average, a few thousandths of one percent uranium. Counts are also produced by cosmic rays which strike the earth from space. Even the materials of which a counter is made have trace amounts of radioactive elements. All this means that a counter is constantly being bombarded by gamma rays, and whenever it is operating, the counter records the normal radioactivity of its surroundings. This is the background count.

Radioactive ore adds radioactivity to the usual background and hence it is the increase in radioactivity above background count that is significant in prospecting.

In looking for radioactive ore, then, the first step is to determine the background count. With a counter having a headset or audio indicator, individual impulses can be counted and totaled for a period of 1, 2, or 3 minutes (the longer periods provide more accurate readings). With a metered counter, the fluctuations of the needle can be visually averaged over a similar length of time.

Background radioactivity changes from time to time and from place to place; hence the background count should be checked periodically. Readings at one spot vary slightly from time to time due to such things as (1) change in cosmic count, (2) change in sensitivity of the counter, and (3) weather changes.

Background count may vary markedly from place to place, due usually to a change in the normal radioactivity of the surface rocks. Igneous rocks, such as granite, are more radioactive than most sedimentary rocks, such as limestone, sandstone, and shale. Among the sedimentary rocks, black shale and phosphate-rich rocks are the most radioactive; pure limestones are the least radioactive; sandstones vary widely in radioactivity. When passing from one rock type to

another, say from limestone to granite, the background count may increase markedly as a result of the change in bedrock.

Absorption Effect

It has been noted earlier that gamma rays from uranium minerals are absorbed by approximately:

3 inches of lead
1 foot of rock
2½ feet of water
Several hundred feet of air.

In one test "80 pounds of high-grade pitchblende ore were placed in a mine working spearated by 2-1/2 feet of solid rock from an adjoining working. No significant radioactivity could be detected through the rock."

Many counter users are prone to overrate the penetrating power of gamma rays. It should always be remembered that almost all the gamma rays that hit the counter come from a surface shell of rock or soil about 1 foot thick; the effect measured by the counter is little more than skin deep regardless of the type of counter.

Cover Effect

Soil or other overburden tends to absorb the gamma rays given off by bedrock. Where soil is more than one or two feet thick, a surface reading gives the radioactivity of the soil, not the underlying rock. Readings are usually higher when taken over a rock exposure than when taken over the same kind of rock covered by soil, provided the soil is derived from the rocks which it covers. The radioactive readings of the soil overlaying a radioactive deposit are due to weathered and broken fragments of the rock in the soil, not to gamma rays passing through the soil.

Cosmic Effect

Cosmic rays are radiation which strike the earth from space. They are important here because they account for some of the radioactivity detected by counters. In a mine or tunnel, cosmic rays are eliminated by absorption and all radioactivity comes from the surrounding rock. Readings made underground may be considerably higher or lower than those at the surface.

Mass Effect

A counter reading may be strongly influenced by the size of the sample tested, particularly if it has above-average radioactivity. A large piece of rock gives off more gamma rays than a small piece, and hence different counter readings can be obtained from specimens of different sizes having the same uranium content.

The mass effect can be demonstrated by comparing the reading obtained from a hand specimen, with a reading taken against the rock face from which the hand specimen was taken and with a reading taken with the counter inserted into a crevice within the rock.

Mass effect is most marked with uranium ores and with rocks of above average radioactivity, such as the granite mentioned above. With rocks of average radioactivity, such as most barren sandstone, little mass effect can be detected, and if cosmic activity is high, a lower reading can be obtained within a rock crevice than with a hand specimen because some cosmic rays are absorbed.

Mass effect is particularly important to the uranium miner because he commonly tests rocks of high radioactivity. Some miners have the impression that a counter which has been checked against a hand sample of known uranium content can be used to directly estimate the grade of an ore pile, it can't!

Natural Radioactivity

In addition to uranium, several other elements are also radioactive, but only two of these - thorium - and radioactive potassium - are sufficiently abundant to create special problems in operating a counter.

Thorium, like uranium, is the parent of a radioactive series which has 11 radioactive members and ends with lead. The gamma activity of the thorium series is about two-fifths that of the uranium series; in other words, rock containing 0.1 percent uranium activates the counter as much as rock with 0.25 percent thorium.

Uranium, thorium and potassium do, however, occur together in igneous rocks, such as granite, and in pegmatite veins which occur in and near granite bodies. Therefore, when prospecting granitic country it should be remembered that some of the measured radioactivity is probably due to thorium, and some may come from potassium. Remember not to forget the value of a chemical assay.

Underground Effect

Mine workings or tunnels present special problems in operating a counter. For example:

1. The instrument is surrounded by rock on all sides and, as a result, the mass effect is intense.

2. Cosmic rays are absorbed by passage through rock and hence their effect is reduced or eliminated in mine workings.

3. Radon contamination may be a problem.

4. In some mines, particularly those which are moist, the rock surfaces are coated with irregular patches of radioactive compounds. These are produced after mining by the action of ground water, which dissolves radioactive salts elsewhere and deposits them by evaporation on exposed rock surfaces and mine faces. Usually these materials are

fluorescent under ultraviolet light. Such radioactive coatings constitute only a thin film and do not represent a minable volume of material, but they may be indicative of nearby radioactive minerals.

Background readings in a mine are usually higher than those over similar rocks at the surface, but sometimes the reverse is true.

THE ULTRA VIOLET LIGHT AND FLUORESCENCE

The Ultraviolet Light

The other instrument of use in uranium prospecting is the portable ultraviolet (U.V.) light. Though not nearly as important as the Geiger or scintillation counter, the U.V. light can be quite valuable. Additionally, the U.V. light can be used in prospecting for many metals and non-metallic minerals that neither contain uranium or thorium or are radioactive.

The ultraviolet light, often called black light or mineral light, is available in two wave lengths. Long wave, which is very similar to the so-called "black lights" used to illuminate fluorescent posters, is the lowest energy level ultraviolet light with a wave length in the area of 3,500 Å. Shortwave, or so called "mineral light", is a higher energy level ultraviolet light with a wave length in the area of 2,500 Å. Some fluorescent minerals react to longwave, many more react to shortwave, including most of those that react to longwave. If you must make a choice, it should be shortwave, however, combination lamps are available.

The internal operation of the U.V. light as well as the physical property of fluorescence in minerals is both beyond the scope of this presentation and need be of little interest to the uranium prospector. It is sufficient to know that, as mentioned earlier, five of the common uranium minerals either always, as in the case of autunite, or occasionally, as in the case of the others, are fluorescent, and; some 50 of the rare or trace uranium minerals sometimes are fluorescent.

Fluorescent Uranium Minerals

Fortunately, the majority of uranium's secondary minerals fluoresce in some shade of yellow-green, ranging from deep yellow to bright green, usually better in short wave. They do not phosphoresce. That is, the fluorescence disappears immediately when the U.V. no longer illuminates the rock. Their dependable glow enables the Geiger operator to move in on a hot formation with the ultraviolet lamp for a close-up look by visual inspection.

The important primary uranium minerals, pitchblende and its crystalline counterpart, uraninite, do not fluoresce. Most deposits, however, are accompanied by at least traces of the secondary minerals, formed by alteration of the primary ore. Thus weathering tends to produce fluorescent streaks on outcrops, and percolating ground water carries these tracers with it creating a trail detectable under U.V.

The thorium minerals show no visible fluorescence, nor do the rare earths, but there are special U.V. tests for certain of these as well as uraninite and pitchblende.

Autunite, a phosphate, is easily uranium's most brilliant fluorescent mineral. At the approach of the lamp, its brittle micalike flakes spring to life with a yellow-green sparkle recognizable at considerable distance.

Tobernite, also a phosphate, contains copper, a well-known quencher of fluorescence, and is not often fluorescent.

Remove the filter from your lamp and you can pinpoint the torbernite by its strongly intensified emerald-green color. A hand lens may show its thin, flat, typically square plates or flakes.

Uranophane, a silicate, usually shows only a faint yellow-green fluorescence or is non-fluorescent. It is not an important ore, often coating rocks with "paint" or fine, fibrous crystals in minute patterns like flower petals.

Schroeckingerite, a sulfate-carbonate, fluoresces bright yellow-green, occasionally a light bluish green, is a very soft and powdery, and dissolves readily in water.

Carnotite, a potassium uranyl vanadate and major ore mineral does not generally fluoresce. It is eyecatching when not too widely disseminated in the sandstone or masked by mineral stains. Remove filter from lamp to make carnotite stand out sharply in contrast to other yellow minerals.

Tyuyamunite, also a calcium uranyl vanadate and generally non-fluorescent, has its yellowish color greatly enhanced by rays from the U.V. lamp with filter removed.

The average uranium-bearing ore you will pick up will probably show its pay mineral as flecks, coatings, or powdery streaks scattered through the matrix.

If your specimen phosphoresces, it is neither uranium nor thorium.

If your fluorescent specimen cannot be scratched with a knife, it is probably not a secondary uranium mineral, most of which can be scratched with the fingernail. Instead, it is probably a filling or coating of chalcedony or common opal, both of which will be fluorescent if they contain as little as .000048% uranium.

Chalcedony and common opal, along with petrified wood, agatized wood, and agatized bone usually exhibit a green fluorescence under short wave U.V. when they contain trace amounts of uranium and this can sometimes be used as a lead to deposits.

GEOLOGIC ENVIRONMENTS AND ARIZONA OCCURRENCES

Uranium is a chemically active element that always occurs in combination with other mineral forming elements. It never occurs naturally in its free or elemental form as do other less reactive metals such as copper, gold and silver, but rather is found as oxides, uranyl vanadates, and in other combinations.

Most chemical analyses for uranium are expressed in percentages of U_3O_8. The radioactivity of uranium makes it possible to detect its presence easily. Under carefully controlled conditions, the approximate amount or concentration can be determined by radiometric instruments such as the Geiger or scintillation counter which measures the emissions from the constant breakdown. Assays based on these readings are expressed as eU or eU_3O_8, and frequently may contain inaccuracies due to lack of equilibrium or due to the presence of other radioactive elements such as thorium or weakly radioactive potassium.

Uranium is present in at least trace amounts in most rocks, and is estimated to make up about two parts per million (2 ppm or 0.0002 percent) of the earth's crust. The average uranium content of most sedimentary rocks approximates that value. Basic igneous rocks (i.e., basalt, gabbro and pyroxenite) tend to be lower, and granitic rocks higher in uranium than the crustal average. The highest concentration of uranium in surface rocks appears in the average volcanic glass (5.6 ppm).

Although an enormous quantity of uranium, literally quadrillions of tons, occurs in the earth's crust, it does not concentrate readily and is not commonly found in sufficient quantities to warrant extraction. The problem then is to locate a concentrated amount of uranium in what we call an ore deposit.

Ore-grade mineralization of uranium is peculiar to certain specific geologic environments. There are several known modes of occurrence that have been or are major sources of uranium. Most of the uranium produced in Arizona occurs or has been mined from five different environments: (1) sandstone, (2) veins, (3) pipes, (4) pegmatites, and (5) placers.

Sandstone Environment

The sandstone-type of deposit has been the largest producer of uranium ore in this country and comprises our largest known reserves. Major sandstone-type producers are well known in the Colorado Plateau province that includes such famous districts as Grants, New Mexico, the Uravan Mineral Belt in southwest Colorado and southeast Utah, and the geologic basins of central and northeast Wyoming. Other producing environments of this general type exist in south Texas, the western Appalachians, and several basins on the east flank of the Appalachians.

The deposits in sandstone consist principally of fine-grained uranium minerals that usually fill the pores of the host rock and replace plant fossils, but also partly replace the sand grains and the cementing minerals of that rock. Geochemically similar elements such as vanadium, chromium, and copper commonly occur with uranium in these deposits.

A majority of the ore bodies are tabular masses that lie nearly parallel to the bedding of the host rocks and are called "peneconcordant". Most peneconcordant deposits are in lenticular sandstone beds that were deposited under continental conditions, chiefly by fresh-water streams. Fossil plant material and sedimentary features in the host sandstone obviously influenced the localization of many of these deposits. The ore deposits range from small masses containing a few tons of ore to large masses containing a million tons or more.

The geologic environment in which the sandstones were formed was typically a low lying delta, alluvial plain, or flood plain or, in some instances, a restricted drainage basin or coastal shoreline where terrestrial sediments were deposited by slow moving, braided and meandering fresh-water streams. Resulting from this environment, generally, are mixed lithologies of sandstone layers interbedded with finer grained rocks of lower permeability: commonly mudstone, siltstone, and, in many cases, argillaceous tuff. Vegetation was rather common as evidenced by the abundance of woody debris found in the sediments.

The source of the uranium and other metallic elements in the ore deposits has been a matter of speculation. There is considerable evidence, however, that the mineralization could have been derived from trace amounts of uranium and vanadium occuring in near-surface rocks or in connate waters. Volcanic ash flows, heavy black sand minerals, and granitic rocks have all been suspected as potential sources of metals. These metals were probably carried in solution in alkaline surface waters and groundwater. As the groundwater moved through the more permeable sandy rocks, the uranium minerals precipitated out upon encountering reducing conditions, such as occur when wood fragments and/or decaying organic material are present.

Vein Environment

A vein is simply a distinct mineralized crack or fissure that cuts across the host rock. The vein may be confined to one type of rock or it may cut through several hosts. The strength of mineralization may be greater in one part of the vein than in another.

Although vein-type uranium deposits are fairly common, it is frequently difficult to determine the origin of the mineralization. Many vein deposits, are derived from a rising hot-water source while others are formed by the concentration of secondary or oxidized minerals dissolved from nearby sources by migrating solutions.

Pipe and Diatreme Environment

Like veins, pipe structures cut through the enclosing rock. The configuration of pipes is different, however, in that they are generally round or oval, in plan view, and essentially vertical in attitude. There are two types of pipe-structures, classified according to origin, that commonly contain uranium. These two include the diatreme and the solution pipe.

The diatreme is actually a volcanic vent explosively blasted through overlying rocks by gas-charged magmas. Characteristically diatremes range from a

few hundred to a few thousand feet in diameter and normally flare out at the surface. At depth they commonly contain breccia, volcanic tuff, and jumbled blocks of country rock. Near the surface, however, diatremes may serve as a restricted sedimentary basin receiving a variety of clastic materials such as sands, silts, and clays.

In Arizona, uranium-bearing minerals in diatremes occur generally in low concentrations and are usually unidentified. The mineralization may be of hydrothermal origin or of redepositional origin from prior solution. The deposits are most commonly small, a few tens of tons, and are not a significant source of uranium .

The solution pipe generally originates by solution of limestone and collapse of the overlying strata into the resultant void. Walls of a solution pipe are generally vertical with breccia-filling in between. In some cases the pipe structures may be closely associated with faults.

Usually mineralization occurs around the perimeter of these collapse structures but in some instances mineral concentrations occur in the brecciated interior. The mineralogy may be simple or complex. Frequently uraninite and secondary uranium minerals occur with copper and iron sulfides and oxides. Lead and zinc minerals may also be present.

Much of the uranium may have been introduced by hypogene sources. However, there is considerable evidence suggesting later solution of the uranium and secondary deposition and enrichment. Some deposits in Arizona are of good grade and moderate size and have contributed significantly to total production.

Pegmatite and Placer Environments

Uranium-bearing pegmatites and placers represent more of a curiosity to the serious prospector than an economic source of mineralization. Complex pegmatites in Arizona have yielded specimen crystal samples of uranium-bearing rare-earth minerals such as allanite, euxenite, and samarskite. Placer accumulations of black sands containing weakly radioactive uranium-bearing heavy minerals such as ilmenite, urano-thorite, and zircon occur locally in Arizona. Under present economic conditions neither of these types of deposits can be mined because generally they are small and/or they contain minerals that require expensive beneficiation techniques.

Arizona Occurrences and Production

The major host rocks of sandstone-type uranium occurrences in Arizona are the Chinle Formation, the Morrison Formation, the Toreva Formation, and some Tertiary lake beds. These rock units have produced more uranium than any other geologic occurrence and are still the most favorable for future prospecting.

Production from the Chinle Formation has accounted for over half of the total uranium ore mined in the State. The bulk of this ore came from the Monument Valley district of northwestern Apache County and northeastern Navajo County. Other districts, Cameron, Vermillion, Little Colorado River Valley, Chinle Valley, and Northern Mohave, have produced smaller tonnages from the Chinle.

Although the Morrison Formation is the major source of uranium in the Colorado Plateau, it does not have extensive outcrops in Arizona and it has produced less than 30 percent of the State's ore. Nevertheless, the Morrison is an important host for uranium in the Northwest Carrizo and Lukachukai Mountains districts. Other districts where uranium-bearing Morrison occurs include North, South, East, and West Carrizo, Redrock Valley, and Chilchinbito-Rough Rock.

Several small low-grade deposits have been mined in the Toreva Formation. Most of these occurrences are in the northeastern corner of Black Mesa, in Navajo and Apache Counties.

Recently attention has been focused on Tertiary or more recent sediments localized in intermontane basins. These sediments, commonly associated with lake deposits, contain interbedded sandstone, shale, mudstone, bentonitic material, gypsum, and volcanic ash or tuff. Frequently plant remains also occur.

These lake-bed deposits may be locally silicified and, in some cases, mineralized with the uranium-bearing mineral carnotite. Although different in some respects, this type of deposit is similar to, and classified as, a sandstone type formation. Major exploration and development, spurred by the high prices of the mid-seventies, of these lake sediments have centered on an area in southwestern Yavapai County (in the vicinity of the Anderson Mine near the Santa Maria river and northwest toward Artillery Peak).

Of the numerous vein-type occurrences of uranium in Arizona, the most notable consist of mineralized fractures in the Dripping Spring Quartzsite of Precambrian age. Abundant radioactive sites are present throughout the rugged Sierra Ancha region of Gila County. The mineralization consisting chiefly of uraninite and secondary uranium minerals, is generally confined to fracture zones associated with diabase dikes and sills intruding the Quartzite.

Although total production from the Dripping Spring is only about 23,000 short tons, the nature of the uranium occurrences appear to be amenable to low cost leaching operations. Such an operation is currently on stream at the Lucky Boy deposit, on the south flank of the Pinal Mountains south of Miami.

Diatremes have produced very little uranium in Arizona. Occurrences are usually small and low grade. Many are clustered in restricted areas of northeast portions of the State.

Solution pipes, however, have a record of significant production. The Orphan deposit, occurring as a collapse structure in the Redwall Limestone of the Grand Canyon region, produced about 500,000 tons of good grade ore. Although attractive in terms of potential, similar deposits may be difficult to locate because of their relatively small areal dimensions and because they are often concealed by younger sediments.

As mentioned earlier, pegmatite and placer deposits in the State represent marginal mineralization at best. Complex pegmatites are fairly common in western Arizona, near Kingman and in the Aquarius Range. Placer-type deposits containing low grade uranium have been reported in heavy mineral concentrations near the Black Mountain Trading Post in Apache County and on the San Xavier Indian Reservation southwest of Tucson.

PROSPECTING

Where To Start

Unlike most valuable minerals, uranium has not been long sought after and prospected for. Uranium prospecting was essentially non-existent prior to the late 1940's. But, in the boom and rush days of the 1950's, prospectors with counters were everywhere and most radioactive outcrops were noted.

Start by researching old literature, especially that published by the old U.S. Atomic Energy Commission and mine files at the Arizona Department of Mineral Resources. Arizona Bureau of Geology and Mineral Technology Bulletin 182 is an excellent over-all data source. Establish a region of interest and re-evaluate the published data in the field yourself. Meet and discuss your ideas with the Engineers and Geologists at the Arizona Department of Mineral Resources and the Arizona Bureau of Geology and Mineral Technology.

What To Look For

When making your ground survey with Geiger or scintillator, mark all radioactive hot spots for later U.V. study, or narrow down the hottest area for later study by night or in daytime under a black cloth about two yards square.

Watch for alteration halos-yellowish or rusty rings around a crystal or embedded rock in matrix. If uranium, the halo may fluoresce. If it does not, it may be an alteration product of thorium. Unusual color changes in nearby rocks are sometimes brought about by uranium or thorium content ranging higher than equivalent ,01 percent uranium as follows:

> Near uranium, quartz is turned smoky, diamond becomes green, coarse calcite assumes a pink color, fluorite turns a deep purple. Green monazite is highly uraniferous, though uraniferous monazite is not always green.
>
> Near thorium minerals, quartz becomes rose-colored. Feldspar has a halo of reddish color around primary uranium or thorium minerals. Radioactive minerals do not cause these always but do so in enough cases to make them useful.
>
> Radiation-damaged zircon crystals sometimes show fluorescent zones, blue or multicolored. Damaged fluorites turn black and evil-smelling; celestite may turn blue, beryl a golden color.

Try to identify the fluorescent tracers, even if they plainly are not uranium. The glow of a lead or zinc mineral, for instance, is an encouraging reminder that lead-zinc ores often are companions of pitchblende.

All interesting spots should be mapped and sampled. Don't make the mistake of not being able to retrace the location of a "hot spot".

The following general suggestions might also prove of value:

1. Reevaluate areas where uranium minerals or anomalous amounts of uranium have already been found.

2. Look for areas of unexplained radioactivity.

3. Investigate geologically favorable areas for the presence of elements commonly found in varying amounts with uranium, such an vanadium, copper, molybdenum, selenium, and arsenic deposits in sedimentary host rocks; or silver, lead, cobalt, nickel, and copper in vein deposits. Aluminum, titanium, and ferric iron are especially lacking and magnetic properties are typically negative.

4. In known uranium-bearing areas, examine extensive sandstone outcrops that are bleached or iron-(limonite)-stained. After radioactivity has been detected, drilling may be warranted if geologic conditions are favorable.

5. Follow known trends rather than testing at random. Large deposits often cluster in elongate trends, which offer better-than-average places to drill, for they may mark the direction in which the ore-forming solutions moved.

6. Investigate the marginal zones of base-metal deposits, which are better places to prospect than the districts themselves.

Prospecting For Sedimentary Deposits

Inasmuch as 96 percent of the uranium deposits of commercial ore in the United States are in sediments that are continental (formed on land) and clastic (fragmental, broken), the following prospecting suggestions that are specific for these deposits are worth emphasizing:

1. Select a uranium province: this refers to the Rocky Mountains, in which nearly all the uranium of the United States has been mined to date.

2. Find, by regional reconnaissance, an ancient or modern basin, 1,000 to 10,000 square miles in area, that was fed by granite wash not too far from its source and that contains tuff (from volcanic ash) and sandstone that was laid down by streams. A positive reading (anomaly), especially of total gamma radiation, recorded from the air is an added sign of encouragement, and each area has its own set of air guides, which should be listed.

3. Look for the following features:

   a. Sandstone or conglomerate:

      (1) Deposited by water - not wind, and thick enough so as to have been deposited over a long time interval.

      (2) Interbedded with mudstone beds, lenses, or zones.

(3) Carbonaceous: medium content of organic matter - "dirty".

(4) Poorly sorted: of different sizes.

(5) Pastel colors: bleached gray, green, buff sandstone, caused by a favorable reducing environment in contrast to red and brown sandstone in an oxidizing environment, which is generally less favorable; the gray versus red color contrast is mostly limited to the Colorado Plateau, except that pink is a good indicator for some deposits of moderate size.

(6) Moderately fractured: permeable enough to have admitted the original solutions but not so permeable as to allow too much leaching away of uranium.

In summary: "continental, fluvioclastic, porous, unconsolidated, carboniferous, arkosic sandstone and conglomerate", "dirty, cherty, trashy, arkosic, mud-seamed sands", with:

(a) Flattening of dipping beds, in the transitional zone between fast-water (sand) and slow-water (silt) deposition.

(b) Halos of uranium anomalies: chemical, radiometric, or mineralogic.

(c) Yellow or black uranium minerals and pyrite.

4. Trace to their sources any anomalous (higher than background or average) occurrence of uranium in stream water or stream bed sediments.

LITERATURE

Sources

Uranium has been the subject of as much or more literature in recent years as any mineral commodity. Resurgency of uranium demand and exploration has caused an increase in the amount of literature presently being published. A tremendous amount has been published by government agencies, in technical journals and as "do-it-yourself" books on prospecting. Much of the literature was published during the early to mid-1950's, the so-called "boom" years and is now out of print.

Many prospecting guides and especially those written on uranium in the 1950's dwell considerably upon mining law and regulations, claim staking procedures, government buying programs and incentives and marketing. However, both government regulations and marketing economics change. The technical staff of Arizona Department of Mineral Resources is always available to discuss the current status of regulations and markets. The uranium prospector is invited to make and keep contact with the Department. Further, every prospector operating in Arizona should have a copy of the Department's Laws and Regulations Governing Mineral Rights in Arizona which explains in detail in everyday language mining laws, regulations and claim staking procedures.

In place of a typical bibliography listing of references at the conclusion of this guide, this chapter will list a number of publications of interest to the independent uranium prospector. The literature is divided into three categories:

1. Location of known occurrences.

2. Geology.

3. Prospecting.

Uranium Occurrences

Available (both in print and out of print but in libraries) information on uranium occurrences in Arizona exist generally in four forms:

1. Individual mine file data at the Arizona Department of Mineral Resources in Phoenix.

2. The uranium chapter in Mineral and Water Resources of Arizona published by the Arizona Bureau of Geology and Mineral Technology in Tucson as Bulletin 180.

3. The uranium section in Coal, Oil, Natural Gas, Helium and Uranium in Arizona also published by the Arizona Bureau of Geology and Mineral Technology in Tucson as Bulletin 182.

4. The U.S. Atomic Energy Commission (now Department of Energy) series of Preliminary Reconnaissance Reports on the various Arizona counties.

All of the above items are available for reference at the Arizona Department of Mineral Resources office in Phoenix. Items 2 and 3 are currently (1978) for sale by the Arizona Bureau of Geology and Mineral Technology, Publications Office, 845 North Park Avenue, Tucson, Arizona 85719. (Item 2 - $4.50; Item 3 - $4.50; plus 10% postage and handling.)

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Uranium Geology

A partial bibliographic listing of literature on the geology of uranium deposits follows. Listings are generally restricted to those of potential value to the prospector.

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Prospecting

Uranium prospecting has been the subject of many books and pamphlets. A number of these were written for the independent prospector, most of which are out of print and available for reference only at libraries and the Arizona Department of Mineral Resources. A partial list of references on uranium prospecting, exploration, geophysics and development follows:

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ARIZONA DEPARTMENT OF MINERAL RESOURCES

The Department was created to aid in the promotion, development, and conservation of the mineral resources of the State. Particular emphasis is placed on providing prospectors and small miners with semi-technical assistance and economic information.

The general goal of the Department is developed by working with the following objectives:

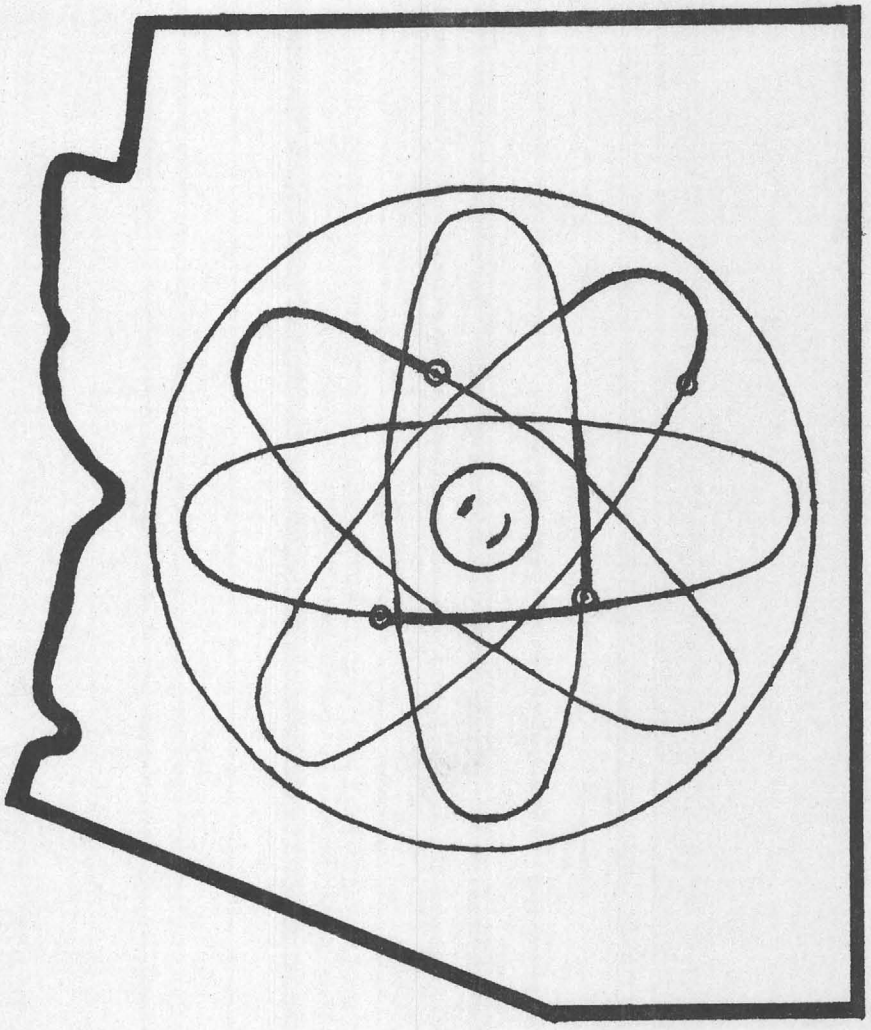
- Provide technical assistance to prospectors and operators of small mines.
- Disseminate comprehensive mining and mineral information to the citizens and government officials of Arizona counties.
- Study conditions regarding small mine activity and seek solutions to problems.
- Serve as the State's public bureau of mining and mineral information.
- Maintain and expand the Department's mine file library.
- Provide educational services in the field of mineral resources and mining.
- Analyse proposed Federal and State administrative actions.
- Develop interagency cooperation between the Department and other local State and Federal offices.
- Gather all information available on mineral occurrences, prospects, partially developed properties and known mines in the State in order to promote further exploration.
- Provide publications in the form of mineral reports, annual directories, technical reports, annual mineral industry surveys, information circulars, and media articles.

SR-1

URANIUM

A PROSPECTOR'S GUIDE

SPECIAL REPORT NO.1



STATE OF ARIZONA

DEPARTMENT OF MINERAL RESOURCES

Special Report No. 1

URANIUM

A PROSPECTOR'S GUIDE

by

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Mineral Resources Engineer

and

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1978

STATE OF ARIZONA

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There are many restrictive environmental and health laws, rules, and regulations that may impede the prospecting for, and the eventual mining and processing of minerals. These laws, rules, and regulations can be either Federal, State, County, or Local, legislated or promulgated and enforced.

Potential problems include disruption of aquifiers, maintenance of air quality, disruption of existing land surface, vegetation and soils, possible conflict of user interest, maintaining workers' health and safety, controlling radiation and modification of socioeconomic patterns (including additional roads, population increase, powerlines, traffic, public services required, etc.)

These possible restrictions should not deter the prospector from actively seeking a mineral deposit or developing an ore body. The highly restrictive rules and regulation problems can be solved. If the potential problems are acknowledged, then solutions engineered into the proposed operation, compliance is possible and feasible. The Department engineers are available to discuss these problems and possible solutions with the prospector or operator.

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URANIUM
A PROSPECTOR'S GUIDE

Arizona Department of Mineral Resources
Special Report Number 1

Introduction

Uranium - A Prospector's Guide has been published by the Arizona Department of Mineral Resources as a guide to the independent prospector in searching for occurrences of uranium. The report discusses uranium prospecting with particular emphasis on the use of radiation detectors (Geiger-Muller and Scintillation Counters) and the ultraviolet lamp. Additional chapters present brief descriptions of the geology and mineralogy of uranium. A number of recommendations for prospecting are given in the chapter on prospecting. The report concludes with a chapter on sources of information and a bibliography.

Voluminous books, guides, reports, maps, etc., have been written on uranium, its mineralogy, geology, occurrences, mining, processing, and use. For maps and descriptions of occurrences, the details of geology, mining laws and regulations, and marketing, the reader is referred to the final chapter on literature and the Arizona Department of Mineral Resources.

The authors wish to acknowledge a number of publications which were invaluable in the preparation of this report. Coal, Oil, Natural Gas, Helium and Uranium in Arizona by H. Wesley Peirce, Stanton B. Keith and Jan Carol Wilt. (Arizona Bureau of Geology and Mineral Technology, 1970) was

of great assistance in the preparation of the chapter on geologic environments and Arizona's uranium position. A great amount of information for the preparation of the chapter on radiation detection was taken from Robert J. Wright's Prospecting With A Counter (U.S., AEC 1954). Data and ideas for the chapter on fluorescence were provided by Sterling Gleason's Ultraviolet Guide to Minerals, (U.V. Products, 1960). Dr. Richard M. Pearl's Handbook for Prospectors, (McGraw-Hill, 1973) was extremely valuable in preparation of the chapter on prospecting and for ideas encompassed throughout the report.

Uranium

Uranium is a metallic element having the chemical symbol U, an atomic number 92, and an atomic weight of about 238.07. It is the last and heaviest member of the natural occurring elements in the Periodic Table. Natural uranium is a mixture of three isotopes, i.e., elements having the same atomic number but differing in atomic weights. These isotopes of uranium are U^{238} (99.285 per cent), U^{235} (0.71 percent), and U^{234} (0.005 percent). These percentages may vary slightly from one geographic source to another. U^{235} is the only naturally fissionable isotope or nuclide of uranium; but under the bombardment by neutrons, the more common isotope, U^{238}, produces plutonium 239 (Pu^{239}) which is another fissionable material. U^{234} is not fissionable and of no importance in atomic energy.

U^{238} and U^{235} are called radioactive because they break down spontaneously at a constant rate into isotopes of other elements by the emission of

charged particles from the nuclei of their atoms. In the breakdown through different series of isotopes or daughter products they end up eventually as stable lead isotopes. The rate of decay is measured in half-lives; 4.51×10^9 (4,510,000,000) years for U^{238} and 7.1×10^8 (710,000,000) for U^{235}.

The use of uranium as a source of energy, first for military purposes and more recently for supplying sustained power, has evolved only within the past forty years. This energy, called nuclear or atomic energy, can be derived from the fission of uranium in which the atomic nucleus of fissionable uranium is hit by a free neutron and splits violently into two different elements and yields a large amount of energy in the form of heat. In this fission only about 0.1 percent of the mass is converted to energy. Theoretically one gram of fissionable uranium could furnish as much heat as three tons of good coal and one pound could supply ten million kilowatt-hours of electrical energy. Nuclear fission releases additional neutrons that can bombard other uranium nuclei and thus set up a continuing process called a chain reaction. The use of neutron-absorbing or moderating materials can control the reaction at the desired rate and the regulated energy released used for producing power, heat, propulsion, and useful fissionable or radioactive materials or isotopes.

Uranium was discovered and named in 1789 and isolated in 1841. Becquerel, in 1896, first noted the radioactive character of uranium. Early experiments with uranium and radioactivity excited little public interest. Uranium salts were used in limited amounts as coloring agents in ceramics

and glass and in specialized photography and luminous paint. The total demand for uranium ore up to the early 1940's never required more than a few hundred tons per year and this had to be high grade material.

World War II and the potential use of uranium in atomic weapons diverted nuclear energy research almost exclusively into military channels, but the successful demonstration of a controlled chain reaction by Fermi and his associates in Chicago in December, 1942, opened the door to the eventual use of uranium as a commercial source of energy for civilian purposes.

GEOLOGIC ENVIRONMENTS AND ARIZONA OCCURRENCES

Uranium is a chemically active element that always occurs in combination with other element-forming minerals. It never occurs naturally in its free or elemental form as do other less reactive metals such as copper, gold, and silver.

Most chemical analyses for uranium are expressed in percentages of U or U_3O_8. The radioactivity of uranium makes it possible to determine its presence, and under carefully controlled conditions, the amount can be determined by radiometric instruments such as the Geiger or scintillation counters which measure the emissions from the constant breakdown. Assays based on these readings are expressed as eU or eU_3O_8, and often contain inaccuracies due to lack of equilibrium or the presence of other radioactive elements such as thorium or weakly radioactive potassium.

Uranium is present in at least trace amounts in most rocks, and is estimated to make up about two parts per million (2 ppm or 0.0002 percent)

of the earth's crust. Most kinds of sedimentary rocks contain close to the average uranium content of the earth's crust, basic igeneous rocks are usually lower, and granitic rocks higher. The highest mean content of uranium in surface rocks appears to be in the average volcanic glass (5.6 ppm).

Although an enormous quantity of uranium, literally quadrillions of tons, occurs in the earth's crust, it is not commonly concentrated in sufficient quantities to warrant extraction. The problem then is to locate a concentrated amount of uranium in what we call an ore deposit.

Ore-grade mineralization of uranium is peculiar to certain specific geologic environments. While some geologically favorable environments may not now be recognized, we can catalogue and describe several known modes of occurrence that have been or are major sources of uranium. Most of the uranium produced in Arizona occurs or has been mined from five different types of environments: (1) sandstone, (2) veins, (3) pipes, (4) pegmatites, and (5) placers.

Sandstone Environment

The sandstone-type of deposit has been the largest producer of uranium ore in this country and is now the largest repository of our known reserves. Major sandstone-type producers are well known in the Colorado Plateau province that includes such famous district as the Grants district in New Mexico, the Uravan Mineral belt in southwest Colorado and southeast Utah, and the basins of central and northeast Wyoming. Other producing environments of this general type exist in south Texas, the western Appalachians,

and several basins on the east flank of the Appalachians.

The deposits in sandstone consist principally of fine-grained uranium minerals that usually fill the pores of the host rock and replace plant fossils, but also partly replace the sand grains and the cementing minerals of that rock. Geochemically similar elements like vanadium, chromium, and copper commonly occur with uranium in these deposits.

A majority of the ore bodies are tabular masses that lie nearly parallel to the bedding of the host rocks and are called "peneconcordant". Most peneconcordant deposits are in lenticular sandstone beds that were deposited under continental conditions, chiefly by fresh-water streams. Fossil plant material and sedimentary features in the host sandstone obviously influenced the localization of many of these deposits. The ore deposits range from small masses containing a few tons of ore to large masses containing a million tons or more.

The geologic environment in which the sandstones were formed was typically a low lying delta, alluvial plain, or flood plain or, in some instances, a restricted drainage basin or coastal shoreline where terrestrial sediments were deposited by slow moving, braided and meandering fresh-water streams. Resulting from this environment, generally, are mixed lithologies of sandstone layers interbedded with finer grained rocks of lower permeability: commonly mudstone, siltstone, and, in many cases, argillaceous tuff. Vegetation was rather common as evidenced by the abundance of woody debris found in the sediments.

The source of the uranium and other metallic elements in the ore deposits

has been a matter of speculation. There is considerable evidence, however, that the mineralization could have been derived from trace amounts of uranium and vanadium occurring in near-surface rocks such as the host rocks and associated rocks, or occurring in the connate waters. Volcanic ash flows, heavy black sand minerals, and granitic rocks have all been suspected as potential sources of the metals.

These metals were probably carried in solution in alkaline surface waters and groundwater. As the groundwater moved through the more permeable sandy rocks, the uranium minerals precipitated out upon encountering reducing conditions such as would occur when wood fragments or decaying organic material were present.

Vein Environment

A vein is simply a distinct mineralized crack or fissure that cuts across the host rock. The vein may be confined to one type of rock or it may cut through several hosts. The strength of mineralization may be greater in one part of the vein than in another.

Although vein-type uranium deposits are fairly common, it is frequently difficult to determine the origin of the mineralization. Many vein deposits, however, are probably derived from a rising hot-water source while others probably formed by the concentration of secondary or oxidized minerals dissolved from nearby sources.

Pipe and Diatreme Environment

Like veins, pipe structures cut through the enclosing rock. The configuration of pipes is different, however, in that they are generally round or oval, in plan view, and essentially vertical in attitude. There are two types of pipe-structures, classified according to origin, that commonly contain uranium. These two include the diatreme and the solution pipe.

The diatreme is actually a volcanic vent explosively blasted through overlying rocks by gas charged magmas. Characteristically diatremes range from a few hundred to a few thousand feet in diameter and normally flare out at the surface. At depth they commonly contain breccia, volcanic tuff, and jumbled blocks of country rock. Near the surface, however, diatremes may serve as a restricted sedimentary basin receiving a variety of clastic materials such as sands, silts, and clays.

In Arizona, uranium-bearing minerals in diatremes occur generally in low concentrations and are usually unidentified. The mineralization may be of hydrothermal origin or of redepositional origin from prior solution. The deposits are most commonly small, a few tens of tons, and are not a significant source of uranium.

The solution pipe generally originates by solution of limestone and collapse of the overlying strata into the resultant void. Walls of a solution pipe are generally vertical with breccia-filling in between. In some cases the pipe structures may be closely associated with faults.

Usually mineralization occurs around the perimeter of these collapse

structures but in some instances mineral concentrations occur in the brecciated interior. The mineralogy may be simple or complex. Frequently uraninite and secondary uranium minerals occur with copper and iron sulfides and oxides. Lead and zinc minerals may also be present.

Much of the uranium may have been introduced by hypogene sources. However, there is considerable evidence suggesting later solution of the uranium and secondary deposition and enrichment. Some deposits in Arizona are of good grade and moderate size and have contributed significantly to total production.

Pegmatite and Placer Environments

Uranium-bearing pegmatites and placers represent more of a curiosity to the serious prospector than an economic source of mineralization. Complex pegmatites in Arizona have yielded specimen crystal samples of uranium-bearing rare-earth minerals such as allanite, euxenite, and samarskite. Placer accumulations of black sands containing weakly radioactive uranium-bearing heavy minerals such as ilmenite, urano-thorite, and zircon occur locally in Arizona. Under present economic conditions neither of these types of deposits can be mined because generally they are small and/or they contain minerals that require expensive beneficiation techniques.

ARIZONA OCCURRENCES AND PRODUCTION

The major host rocks of sandstone-type uranium occurrences in Arizona are the Chinle Formation, the Morrison Formation, the Toreva Formation,

and some Tertiary lake beds. These rock units have produced more uranium than any other geologic occurrence and are still the most favorable for future prospecting.

Production from the Chinle Formation has accounted for over half of the total uranium ore mined in the State. The bulk of this ore came from the Monument Valley district of northwestern Apache County and northeastern Navaho County. Other districts, Cameron, Vermilion, Little Colorado River Valley, Chinle Valley, and Northern Mohave, have produced smaller tonnages from the Chinle.

Although the Morrison Formation is the major source of uranium in the Colorado Plateau, it does not have extensive outcrops in Arizona and it has produced less than 30 percent of the State's ore. Nevertheless, the Morrison is an important host for uranium in the Northwest Carrizo and Lukachukai Mountains districts. Other districts where uranium-bearing Morrison occurs include North, South, East, and West Carrizo, Redrock Valley, and Chilchinbito-Rough Rock.

Several small low-grade deposits have been mined in the Toreva Formation. Most of these occurrences are in the northeastern corner of Black Mesa, in Navajo and Apache Counties.

Recently attention has been focused on Tertiary or more recent sediments localized in intermontane basins. These sediments, commonly associated with lake deposits, contain interbedded sandstone, shale, mudstone, bentonitic material, gypsum, and volcanic ash or tuff. Frequently plant

remains also occur.

These lake-bed deposits may be locally silicified and, in some cases, mineralized with the uranium-bearing mineral carnotite. Although different in some respects, this type of deposit is similar to, and classified as, a sandstone-type formation. Major exploration and development, spurred by the high prices of the mid-seventies, of these lake sediments have centered on an area in southwestern Yavapai County, in the vicinity of the Anderson mine near the Santa Maria river and northwest toward Artillery Peak.

Of the numerous vein-type occurrences of uranium in Arizona, the most notable consist of mineralized fractures in the Dripping Spring Quartzite of Precambrian age. Abundant radioactive sites are present throughout the rugged Sierra Ancha region of Gila County. The mineralization consisting chiefly of uraninite and secondary uranium minerals, is generally confined to fracture zones associated with diabase dikes and sills intruding the Quartzite.

Although total production from the Dripping Spring is only about 23,000 short tons, the nature of the uranium occurrences appear to be amenable to low cost leaching operations. Such an operation is currently on stream at the Lucky Boy deposit, on the south flank of the Pinal Mountains south of Miami.

Diatremes have produced very little uranium in Arizona. Occurrences are usually small and low grade. Many are clustered in restricted areas of

northeast portions of the State.

Solution pipes, however, have a record of significant production. The Orphan deposit, occurring as a collapse structure in the Redwall Limestone of the Grand Canyon region, produced about 500,000 tons of good grade ore. Although attractive in terms of potential, similar deposits may be difficult to locate because of their relatively small arial dimensions and because they are often concealed by younger sediments.

As mentioned earlier, pegmatite and placer deposits in the State represent marginal mineralization at best. Complex pegmatites are fairly common in western Arizona, near Kingman and in the Aquarius Range. Placer-type deposits containing low grade uranium have been reported in heavy mineral concentrations near the Black Mountain Trading Post in Apache County and on the San Xavier Indian Reservation southwest of Tucson.

ECONOMIC URANIUM MINERALS

Minerals

Minerals are the building blocks of which the lithosphere (solid rock portion) of the earth is constructed. Over 2,500 such substances have been recognized and described by trained mineralogists. Of these only a few hundred are of commercial consequence in our metallic, non-metallic and energy industries. Around 200 uranium and thorium mineral species have been recognized. However, the uranium prospector needs to only recognize less than ten of these to be effective. The recognition and identification of all minerals is based upon certain fundamental concepts including:

(a) Minerals are naturally occurring

(b) Minerals are inorganic chemical compounds

(c) Minerals are homogeneous (all parts of a given mineral are alike).

(d) Each mineral possesses rather definite physical properties such as, hardness, color, luster, etc.

(e) The chemical compostion is sufficiently constant that simple formulas may be written for it.

A mineral's physical properties are the prospector's most useful keys in their recognition and identification. These properties are: (1) radioactivity; (2) fluorescence; (3) luster; (4) habit; (5) specific gravity; (6) color (7) cleavage and fracture and (8) hardness. A discussion of these physical properties as they pertain to the recognition of uranium minerals of interest to the prospector follows.

Radioactivity

Certain minerals, including all those containing the elements uranium and thorium and some others, spontaneously emit small particles of matter from their atoms in a process called radioactivity. Special techniques are required for recognition of this property, and this most important aspect of uranium minerals and uranium prospecting will be discussed more thoroughly later.

Color

Most of the more common uranium minerals have a distinctive color and visual examination alone is a significant aid in recognizing minerals.

The color of a mineral is largely the result of its chemical composition. The secondary (more about that term later) commercial uranium minerals often exhibit bright hues of yellows and greens while the primary uranium minerals range from dark greenish to black.

Luster

Luster is the appearance of a freshly broken surface of a mineral in reflected light. Some of the most common distinctions include:

(a) Metallic - surface reflection like a metal

(b) Glassy - looks like the surface of bright glass

(c) Greasy - reflection similar to an oily surface

(d) Silky - Appearance of silk in light

(e) Resinous - like resin, almost waxy

(f) Pearly - like mother-of-pearl

(g) Dull - reflects little light (for example, clay)

(h) Earthy - no noticeable reflection of light

(i) Pitchy - like pitch or tar

The uranium minerals have, for the most part, earthy, pearly, glassy, dull or pitchy lusters.

Habit

The habit of a mineral refers to the characteristic form assumed by a mineral as found in the field including its general shape and irregularities of growth. The habit of minerals may be as crystals (definite shapes such as

cubes, pyramids, prisms, etc.), rounded grains radiating groups, nodules, banded, massive, etc. The common habits for the uranium minerals are plates or scales, earthy masses and coatings.

Specific Gravity

Specific Gravity or "heft" is the comparative weight of a volume of a mineral to the weight of an equal volume of water. The specific gravity of water is arbitrarily set at "one". If a mineral has a specific gravity of 3.5, a given volume of the mineral weighs 3.5 times the same volume of water. The specific gravity or common rock is about 2.6. Any mineral or rock of significantly greater heft (heavier than the same sized piece of common rock) should arouse any prospector's (uranium or otherwise) interest. Specific gravity values for pure uranium minerals range from 3 to 10. However, since most uranium minerals occur mixed with other minerals or as very thin coatings on average heft rocks, valuable uranium ores may not necessarily have significantly high specific gravities.

Fluorescence

Fluorescence is the property of a substance to emit visible light in a darkened space when acted upon by ultra-violet light. Special mineral lights or black lights are used for this purpose. Fluorescence has been detected in some specimens of about 600 different mineral species. A few nearly always exhibit fluorescence, many only rarely. Five of the uranium minerals on the chart either always or occasionally are fluorescent. In addition there

are about 50 rare or trace uranium minerals "the so called uranium ochers", (color halos) that are sometimes fluorescent and may provide a clue to the presence of economic uranium minerals. Fluorescence will also be discussed further.

Cleavage and Fracture

The orderly arrangement of the elements (such as uranium, thorium, oxygen, etc.) into minerals builds a strong atomic structure in certain directions and weak structures in others. When a mineral breaks with ease along the weak directions a smooth surface is usually produced which readily reflects light. This property of ease of breaking into plain-like forms is called cleavage. It may be in one or more directions. If the mineral breaks unevenly or with a curved, shell-like (conchoidal) surface, this property is known as fracture. Some uranium minerals have three directions of cleavage, some two, some one and others show no cleavage but conchoidal to uneven fracture instead.

Hardness

The hardness of a mineral is an expression of its resistance to abrasion or to scratching. It ranges on an arbitrary scale from "one" (soft like talc) to "ten" (hardest substance known, diamond). A mineral with a hardness of "one" will mark the flesh of the hand or a piece of paper. The finger nail is about "two;" a copper penny, "three;" a steel knife blade, "five;" and window glass between "five" and "six" (5.5) in hardness. The mineral, quartz, has a hardness of "seven" and there are only a few minerals which are harder.

If the minerals occur as small aggregates, coatings or are powdery in nature, the hardness determinations will be difficult, inconclusive and of little use. Otherwise it is a simple matter to relate scratching ability to the common articles named above. A mineral which may scratch a finger nail but will be scratched by a penny is said to have a hardness of between "two" and "three" or simply 2.5, etc.

Most of the uranium minerals in pure crystalline or massive form have a hardness of less than "six;" the brighter-colored oxides of uranium range from "two" to "three."

URANIUM MINERALS

The uranium minerals are divided by geologists into two general classes: primary and secondary. Most primary minerals are those that have been formed by heated gases and solutions coming up from deep within the earth. Secondary minerals have been formed by alteration of the primary minerals as a result of the weathering action of ground waters or other natural processes. Primary uranium minerals are readily altered to the secondary varieties as a result of this chemical action.

Primary uranium minerals usually occur in vein deposits (tabular bodies), pegmatites (coarse-grained igneous dike rocks) and mixed with secondary uranium minerals in Colorado Plateau sedimentary deposits. They are generally dark-brown to black, have a high specific gravity, and usually a dull, pitchy luster.

A brief description follows for each of the common ore-making uranium minerals:

Primary Uranium Minerals

Uraninite, including its massive impure variety. Pitchblende, is the most important primary (sometimes secondary) uranium mineral. Uraninite is found in isolated crystals and masses in veins and dikes. It is also found as stringers, lenses and blebs filling cavities in rocks and occasionally is disseminated as dustlike grains similar to carbon dust. Uraninite is essentially uranium oxide with a variable uranium content of 46 to 88 percent. Pitchblende often occurs in rounded, irregular masses, and then breaks with a curved (concoidal) surface as does glass. Pitchblende is heavier then steel, about as hard, and is grayish or greenish black.

Coffinite is a significant uranium mineral in many of the Colorado Plateau sandstone uranium deposits. When found in such deposits it is typically associated with pitchblende. Further its physical characteristics are very similar to those of pitchblende (See Table 1).

The other major, so called primary uranium minerals, brannerite and davidite are rare enough as to not need consideration here.

Secondary Uranium Minerals

The secondary uranium minerals are characterized by their bright colors, including yellow, orange, and green. They usually occur as earthy or powdery masses, as groups of very small crystals, or as flat plates.

The secondary minerals are present in almost any type of rock, and may or may not be found with primary minerals. A few of the more common secondary minerals are carnotite, tyuyamunite, autunite and torbernite.

Carnotite is generally considered the most important secondary uranium mineral. Carnotite is a hydrated potassium uranium vanadate. It is bright yellow in color with an earthy appearance and an indeterminate hardness. As it is often very difficult to distinguish between carnotite and a great variety of other less common yellow uranium minerals, carnotite is a useful descriptive name for the group.

Tyuyamunite resembles carnotite but is more greenish-yellow and may fluoresce yellow to a weak apple green.

Autunite is a bright lemon-yellow material. It is soft and occurs in small flat and translucent crystals. It always fluoresces to a bright yellow or apple green when exposed to ultraviolet light.

Torbernite and meta-torbernite are bright green minerals. They are soft and occur in flat transparent crystals.

TABLE 1

CHARACTERISTICS OF COMMON ECONOMIC URANIUM MINERALS

NAME & CHEMICAL COMPOSITION	COLOR	LUSTER	HABIT	FLUORES-CENCE	HARDNESS & (SPECIFIC GRAVITY)	CLEAVAGE (FRACTURE)
PITCHBLENDE (Uranium Oxide)	Grayish black; Greenish black	Pitchlike, dull, earthy or glassy	Massive; rounded surface; banded	None	5 to 6 (6 to 9)	(Conchoidal or Uneven)
URANINITE (Uranium Oxide)	Grayish-black; Greenish-black; Brownish-black	Pitchlike; dull; or glassy	Small cube-like crystals; massive	None	5 to 6 (8 to 10)	(Conchoidal or Uneven)
COFFINITE (Hydrated silicate of uranium)	Black, pale to dark-brown	Dull to adamantine	Fine aggregates; disseminations; small bodrgoidal	None	5 to 6 (5)	(Conchoidal or Uneven)
SAMARSKITE (Complex mineral containing uranium and rare earths)	Liver-brown	Glassy	Massive; coarse crystals; radiating crystals	None	5 to 6 (4 to 6)	(Conchoidal or Uneven)
CARNOTITE (Potassium uranium vanadate)	Canary-yellow	Earthy; pearly	Earthy masses; thin coatings	Yellow Short-wave	2 to 3 (4 to 5)	One Direction
TYUYAMUNITE (Calcium uranium vanadate)	Greenish-yellow	Earthy; pearly	As scales; thin coatings; earthy	None; or weak apple green	2 to 3 (3 to 4)	Three Directions
AUTUNITE (Calcium uranium phosphate)	Lemon-yellow; sulfur-yellow; apple-green	Pearly	Thin plates; micaceous; earthy	Brilliant yellow; or apple green	2 to 3 (3)	One Direction

Common Economic Uranium Minerals

NAME & CHEMICAL COMPOSITION	COLOR	LUSTER	HABIT	FLUORES-CENCE	HARDNESS & (SPECIFIC GRAVITY)	CLEAVAGE (FRACTURE)
URANOPHANE (Calcium uranium silicate)	Lemon-yellow; pale greenish, straw or orange yellow	Pearly; greasy	Radiating aggregates; fibrous; or massive	None; or faint green	2 to 3 (4)	Two Directions
GUMMITE (Complex hydrated oxide of lead and uranium)	Yellow to deep orange or brown; of variable color	Dull; waxy; greasy; glassy	Massive; as crusts	None	2 to 3 (4 to 6)	(Conchoidal or Uneven)
TORBERNITE And METATORBERNITE (Copper uranium phosphate)	Bright green; Emerald-green; Apple-green	Pearly	Mica-like square crystals; soft masses	None; or faint green	(3 to 4)	Two Directions
MONAZITE (Cerium and rare earth phosphate)	Golden-yellow yellowish; reddish or greenish-brown	Resinous	Flattened or tabular crystals	None	5 to 6 (4 to 5)	Good (Conchoidal or Uneven)

RADIATION DETECTION

Name your locality and the chances are favorable that uranium minerals may be found. But, that's no promise they'll be in commercial amounts or minerals from which the uranium can be feasibly recovered. Few other elements are known to occur in as many types of geological settings as uranium. This, happily, is good, for it means that many deposits may have been overlooked. One of the most active uranium prospecting and exploration regions in Arizona; at present, the Bill Williams River - Date Creek Basin area of northern Yuma and southwestern Yavapai Counties was of little interest 25 years ago.

Before discussing prospecting and field procedures two pieces of equipment should be discussed. They are the radiation counter and the ultraviolet light. By far the most important of the two for uranium prospecting is the radiation counter. Although not an absolute necessity, radiation detection instruments are so valuable in radioactive-mineral prospecting that the subject is scarcely worth discussing without them.

Dr. Richard Pearl in his Handbook for Prospectors (5th edition, McGraw-Hill Book Company, 1973) introduces the subject of prospecting with a radiation counter by stating three basic principles:

1. Although it is probably true that any child can operate a Geiger counter, it takes a certain amount of experience and judgment to use it effectively.

2. Although the Geiger counter (and its more sensitive relative, the scintillation counter) is a modern effective electronic device, the commercial value of radioactive ores is determined by chemical analysis. The counters, therefore, merely indicate the presence of a reaction, they do not provide actual evaluation of uranium content without additional data.

3. These instruments are detectors of radioactivity in general, yet only uranium, and to a much lesser extent thorium, have any significant value. In addition to uranium and thorium, potassium as well many other elements are sometimes radioactive, and the surface of the earth is continually receiving cosmic radiation, all of which influence the readings on radiation counters.

Lest these three points discourage you, remember uranium prospecting can be profitable, and it can be easier than prospecting for most other types of minerals. The instruments can do most of the work for you, provided you do the thinking! No kind of prospecting is profitable let alone safe for a nitwit.

Atomic Radiation

To effectively use a Geiger or scintillation counter (they will both be described shortly) it is desirable to understand something about radioactivity. This is the spontaneous automatic breakdown (disintegration, decay) of chemical elements as they change into other lighter elements. Every natural element has at least one isotope that is radioactive, and all the man made

elements are radioactive. For prospecting purposes only uranium, thorium and sometimes potassium are of concern. Both uranium and thorium decay finally to lead, which is the stable (nonradioactive) end of the decay series. During the transformations that takes place, heat is generated, helium gas is given off, subatomic particles are emitted, electromagnetic radiation is emitted, and a number of intermediate "daughter elements" or "daughter products" are formed, which in turn break down radioactivity.

The radiation that is produced by this natural process cannot be hastened or delayed by pressure, heat, or chemical means and is constant during the passage of time. It consists of alpha and beta particles, and gamma rays. Alpha particles are positively charged particles of weak penetrating power, (essentially a helium nucleus); beta particles are negatively charged particles of somewhat greater penetrating power; essentially an electron and gamma rays are uncharged electromagnetic radiation, being true rays like powerful X-rays, light rays, etc. The Geiger and scintillation counters record chiefly gamma rays, and some prospecting devices measure beta radiation.

You should be aware that, although some important uranium minerals are luminescent and will glow in ultraviolet light, this effect is not caused by radioactivity, which is invisible. Neither are there any magnetic properties that might influence a watch or compass. The radiation is also soundless, itself.

Regardless of their apparent variety, radiation counters for use in

prospecting belong to two fundamental types. These are the Geiger counter, and the scintillation counter. Because of its higher sensitivity, the scintillation counter is probably as popular as the Geiger counter in spite of its higher cost. Other types of radiation detectors such as the ionization chamber, spinthariscope, the radioscope and electroscope have been used in prospecting, but have not proved popular and hence are not discussed here.

Geiger Counter

The Geiger-Muller counter was developed as a sensitive device for measurements of radioactivity in the laboratory. The first field instruments were clumsy, but the modern prospecting counter is a compact, rugged instrument. Specialized counters have been designed for a variety of specific jobs, such as prospecting from the air, examining bore-holes, and radiometicly probing ore shipments.

The heart of the Geiger counter is the Geiger tube. It is made of metalized glass or metal and may be from a few inches to several feet in length.

In some counters, the Geiger tube is contained within the counter case, whereas in others the tube is separate, and connected to the case by a conducting cable. The tube is filled with one or more gases, such as helium, argon, or krypton, and in operation a positive charge of about 1,000 volts is applied between the glass or metal shell a center wire.

A radioactive element such as uranium emits either alpha or beta particles and may emit gamma rays as well. When a Geiger counter is

placed near such an element the tube is struck by the radioactive emissions. Alpha particles are stopped by the tube wall and cannot affect the tube. Beta particles have greater penetrating power and some of these can enter the tube and be recorded. Gamma rays, which are still more penetrating, can penetrate the wall, but most pass completely through the tube with no effect. A few gamma rays-about one half of one percent - enter the tube and collide with a molecule of the enclosed gas to produce electrons. The negative electrons thus produced are attracted toward the positively charged center wire and produce a negative electrical pulse as they strike the wire.

In addition to the tube, a Geiger counter contains a battery-operated power supply, an amplifier, and one or more indicators. The indicator may be a neon light, or a meter, which gives a visible indication of radioactivity, or a headset, or speaker which gives an audible indication. The light flickers and the earphone clicks each time the Geiger tube discharges. The meter gives an average measurement of radioactivity.

Scintillation Counter

It was noted above that a Geiger detects gamma and occassionally beta rays by the ionizing effect they have upon gases contained within the Geiger tube. A scintillation counter, like the Geiger counter, also measures gamma and occassional beta rays, but it depends upon another property: the ability of gamma (and beta) rays to produce tiny momentary flecks of light (scintillations) in crystals of certain compounds such as sodium iodide and potassium iodide.

The chief advantage of a scintillation counter is that if responds to a large proportion of the gamma rays that hit the crystal. Depending on the type and size of the crystal, scintillations are produced by 50 percent or more of the gamma rays that strike the crystal. In contrast, most Geiger tubes are discharged, as stated before, by less than 0.5 percent of the gamma rays which penetrate them. This means that the crystal counter is more sensitive.

The arrangement of component parts is similar in both types of counters. In place of the Geiger tube, a scintillation counter employs a small crystal, usually made of sodium iodide, attached to the end of a light-sensitive photomultiplier tube. Both crystal and photomultiplier tube are sealed in a light-tight unit so that the instrument cannot be triggered by sunlight. The tube "sees" the scintillations produced in the crystal and transmits them as electrical pulses. These are amplified and passed through an averaging circuit to a recording meter.

Using Radiation Detectors

A few general suggestions about the use of a Geiger or scintillation counter should be made:

1. Because of the high voltage necessary to charge the Geiger tube, or operate the photomultiplier tube, it is important that the equipment be kept dry, otherwise the counter may short out. Some instruments are especially sealed by the manufacturer against moisture, but unless this has been done

the counter should not be used in a humid environment, such as a wet mine.

2. The counter should be protected from contamination by radioactive clothing, mine or mill dust or ore specimens.

3. If individual clicks cannot be distinguished in the earphones or the needle swings to the top of the indicating dial, the radioactive field maybe so intense that the counter might be damaged. Use a less sensitive counter setting or move away from the source of radioactivity.

4. The counter should of course be turned off when not in use in order to conserve the batteries.

5. To obtain an accurate reading, keep the counter away from any watch, compass, or other instrument which has a luminous dial. The luminous paint contains a radioactive radium compound.

A Geiger counter is adequate for most geologic and mining problems. However, the higher sensitivity of a (crystal) counter makes it especially useful for measuring low levels of radioactivity, for making radioactivity surveys, and for prospecting from the air.

Many kinds of counters are manufactured for field use and before purchasing one, the user should determine which type most nearly fits his needs and pocketbook.

Gamma Radiation

Since the discovery of radioactivity in 1896, researchers have attempted to determine the nature of the emissions produced. In the course of this work many types of radiations have been discovered: alpha particles, beta particles,

gamma rays, protons, positrons, neutrons, mesons, neutrinos. Of these, gamma rays are of most importance in the present discussion because field counters are mainly gamma ray detectors. Some Geiger counters have a metal sleeve which can be moved to expose the Geiger tube directly to radiation, but only in this way can a few of the many other particles be detected.

Gamma rays are like X-rays. They:

1. travel in straight lines at the speed of light
2. produce scintillations in certain crystals
3. have neither mass nor charge
4. blacken photographic film
5. penetrate matter
6. ionize gases

Like X-rays, gamma rays can penetrate matter, but the gamma rays produced by uranium minerals have only slight penetration due to their relatively low-energy level. The ease with which gamma rays are absorbed by any material depends on its density. The gamma rays from uranium are stopped by approximately:

3 inches of lead

1 foot of rock

2 1/2 feet of water

several hundred feet of air

Since the outer foot of a rock mass absorbs almost all gamma radiation beneath it, a counter cannot detect gamma rays which come from a source

deeper than one foot. Once the rays escape from the rock, however, they can travel for some distance through air. In other words, a counter measures only the gamma rays from the outer one foot rock shell and it cannot detect radioactive ores deep within a rock mass. This is a very important limitation on the usefulness of a counter.

To understand the uses and limitations of counters, it is necessary to know a few facts about uranium and its many radioactive daughter products.

Several elements, as mentioned earlier are naturally, unstable and these undergo spontaneous radioactive decay.

Uranium ore contains two kinds of uranium atoms (isotopes really) - one with atomic weight of 238 and the other with atomic weight of 235. Uranium - 238 is much more abundant than uranium - 235, by a ratio of 140 to 1. Because of its greater abundance, uranium - 238 is largely responsible for the radioactivity of uranium ore.

When uranium - 238 disintegrates, it forms thorium - 234. This, too, is radioactive and decays to form protactinium - 234, also a radioactive element. Other radioactive elements are formed by this progressive disintegration until finally an inactive element, lead, is formed. Thus, uranium - 238 is the parent element of a long series of radioactive elements. Each is formed by radioactive decay and each yields another radioactive element. The series begins with uranium - 238 and includes 13 radioactive daughter elements, one of which - radon - is a gas. The series ends with lead, which is inactive and undergoes no further decay.

The radioactive decay series for uranium 238 is: Uranium - 238; Thorium - 234; Protactinium - 234; Uranium - 234; Thorium - 230; Radium - 226; Radon - 222; Polonium - 218; Lead - 214 (radioactive lead); Bismuth Polonium - 214; Lead - 210; Bismuth - 210; Polonium - 210; and Lead - 206, which is stable.

Each element emits either an alpha or a beta particle, and in addition, five of the elements are gamma emitters. These five are thorium - 234, protactinium - 234, radium - 216, bismuth - 214, and lead 210. Bismuth 214 and protactinium 234 are the strongest gamma emitters.

It is important to note that uranium itself does not give off gamma or beta rays. Therefore the Geiger counter, which is primarily sensitive to gamma rays, cannot detect uranium directly. Instead, the counter measures the radiations of the five gamma ray producers, particularly the strong emitters Bismuth - 214 and protactinium. Only when the gamma ray emitters are present in amounts proportional to the amount of uranium can the counter give an accurate measure of the uranium present.

Table 2 -- The Uranium Series

Element	Radiometric Designation	Half Life	Radiations (mev.) Alpha	Beta	Gamma
Uranium-238	UI	4,510,000,000 years	4.21		
Thorium-234	UX_1	24.1 days		0.18	0.09
Protactinium-234	UX_2	1.1 minute		2.32	0.80
Uranium-234	UII	269,000 years	4.75		
Thorium-230	Ionium (Io)	82,200 years	4.66		
Radium-226	Radium (Ra)	1,600 years	4.79		0.19
Radon-222	Radon (Rd)	3.8 days	5.49		
Polonium-218	Radium A (RaA)	3.1 minutes	5.99		
Lead-214	Radium B (RaB)	26.8 minutes		0.65	
Bismuth-214	Radium C (RaC)	19.7 minutes		3.15	1.8
Polonium-214	Radium C' (RaC')	0.0002 second	7.68		
Lead-210	Radium D (RaD)	22.2 years		0.025	0.047
Bismuth-210	Radium E (RaE)	5.0 days		1.17	
Polonium-210	Radium F (RaF)	139 days	5.30		
Lead-206	Radium G (RaG)	Stable			

Radioactive Equilibrium

This is a fact of prime importance, since it is a limitation on the accuracy of any uranium analysis made by measuring radioactivity.

Under what conditions, then, are the gamma ray emitters present in normal amounts? They are present in normal amounts if the material tested is in radioactive equilibrium.

What is meant by radioactive equilibrium? When uranium is freshly purified and isolated from its radioactive daughter elements, it immediately starts to decay to form its daughter elements. As these progressively decay all the elements in the decay series gradually accumulate. Finally, after about 1 million years, each element is present in such amount that it decays at the same rate as it is produced, and thereafter no further change takes place in the quantity of any daughter element. The series is then in radioactive equilibrium. When uranium ore is in equilibrium, a fixed proportion of each daughter element is present, whether the ore contains 0.1 percent uranium or 50 percent uranium. At equilibrium each gamma emitter is present in its normal amount and the radioactivity measured by a counter is dependent on the amount of uranium present; hence, a counter reading can provide a reliable indication of the uranium contained in the ore.

When is a uranium sample in equilibrium?

Of first importance is the fact that about 1 million years are required for newly purified uranium to reach equilibrium with its daughter products. All the uranium now contained in rocks was, assumed, present when the earth

was formed. Since the earth is estimated to be 4,500 million years old, all uranium in the earth is also assumed to be of this same age. It might then be expected that uranium everywhere should be in equilibrium. This would be the case if it were not for the fact that some uranium-bearing materials have undergone chemical or physical change which has separated the uranium from its daughter elements. If this change took place within the past 1 million years, insufficient time has elapsed for the separated uranium to establish equilibrium again.

Lack of equilibrium, then, results from the separation of uranium from its daughter elements within the last 1 million years. In nature this can result from (1) attack by solutions (such as ground water) and (2) the loss of the gaseous daughter element radon. The first of these is important in many geologic problems, but the second is important only under special conditions.

Nonequilibrium due to attack by solutions is a common result of the oxidation and weathering of outcropping uranium deposits, especially deposits which contain pitchblende and sulphide minerals (such as pyrite, chalcocite, and chalcopyrite). Ores of this type are found in many places throughout the Southwest. Oxidation of pitchblende-sulphide ore forms acidic ground water due to the formation of sulphuric acid by the oxidation of the sulphide minerals. Uranium is soluble in acid waters and tends to be removed in solution, but radium is much less soluble and its compounds tend to remain behind in the leached outcrop. Therefore, the outcrop may be radioactive due to the presence of the gamma-emitting elements Bismuth - 214 and Lead - 210, even

though much of the uranium has been lost in solution. As a result, a sample taken from the outcrop may give a high counter reading, but a chemical analysis proves that the uranium content is low.

In places secondary uranium minerals - such as autunite, torbernite, and schroeckingerite - are deposited by ground water. Most such deposits are out of equilibrium. The equilibrium conditions usually vary widely from sample to sample and therefore counter readings are apt to be quite unreliable. Lack of equilibrium in these secondary minerals results from the fact that the minerals were deposited less than 1 million years ago. Hence, gamma-emitting daughter elements have not yet accumulated in their equilibrium amounts, and more uranium may be present than is suggested by the counter readings.

Movement of radon - 222, the second cause of nonequilibrium, is much less important than the effect of solution. Radon is one of the daughter elements of uranium. It is a heavy gas with half life of 3.8 days. Being a gas, radon can move by gaseous diffusion. Within rocks it normally diffuses only very short distances because of its comparatively short half life; after 5 half lives (approximately 20 days) radon is almost completely disintegrated to polonium - 218, a solid element, and further gaseous diffusion is stopped.

The effects of radon - 222 are most noticeable in confined spaces such as mine workings, tunnel, drill holes, etc.

In the actual use of a Geiger or scintillation counter a number of practicle problems need to be brought out. They are, in addition, to the equilibrium and radon gas effects all ready discussed: (1) background effect,

(2) absorption effect, (3) cover effect, (4) cosmic effect, (5) mass effect, (6) thorium effect and (7) underground effect.

Background Effect

Most things are slightly radioactive. All rocks carry, on the average, a few thousandths of one percent uranium. Counts are also produced by cosmic rays which strike the earth from space. Even the materials of which a counter is made have trace amounts of radioactive elements. All this means that a counter is constantly being bombarded by gamma rays, and whenever it is operating, the counter records the normal radioactivity of its surroundings. This is the background count.

Radioactive ore adds radioactivity to the usual background and hence it is the increase in radioactivity above background count that is significant in prospecting.

In looking for radioactive ore, then, the first step is to determine the background count. With a counter having a headset or audio indicator, individual impulses can be counted and totalled for a period of 1, 2, or 3 minutes (the longer periods provide more accurate readings). With a metered counter, the fluctuations of the needle can be visually averaged over a similar length of time.

Background radioactivity changes from time to time and from place to place; hence the background count should be checked periodically. Readings at one spot vary slightly from time to time due to such things as (1) change in cosmic count, (2) change in sensitivity of the counter, and (3) weather changes.

Background count may vary markedly from place to place, due usually to a change in the normal radioactivity of the surface rocks. Igneous rocks, such as granite, are more radioactive than most sedimentary rocks, such as limestone, sandstone, and shale. Among the sedimentary rocks, black shale and phosphate-rich rocks are the most radioactive; pure limestones are the least radioactive; sandstones vary widely in radioactivity. When passing from one rock type to another, say from limestone to granite, the background count may increase markedly as a result of the change in bedrock.

Absorption Effect

It has been noted earlier that gamma rays from uranium minerals are absorbed by approximately:

3 inches of lead

1 foot of rock

2 1/2 feet of water

several hundred feet of air

In one test "80 pounds of high-grade pitchblende ore were placed in a mine working separated by 2 1/2 feet of solid rock from an adjoining working. No significant radioactivity could be detected through the rock."

Many counter users are prone to overrate the penetrating power of gamma rays. It should always be remembered that almost all the gamma rays that hit the counter come from a surface shell of rock or soil about 1 foot thick; the effect measured by the counter is little more than skin deep regardless of the type of counter.

Cover Effect

Soil or other overburden tends to absorb the gamma rays given off by bedrock. Where soil is more than one or two feet thick, a surface reading gives the radioactivity of the soil, not the underlying rock. Readings are usually higher when taken over a rock exposure then when taken over the same kind of rock covered by soil, provided the soil is derived from the rocks which it covers. The radioactive readings of the soil overlaying a radioactive deposit are due to weathered and broken fragments of the rock in the soil, not to gamma rays passing through the soil.

Cosmic Effect

Cosmic rays are radiation which strike the earth from space. They are important here because they account for some of the radioactivity rays. In a mine or tunnel cosmic rays are eliminated by absorption and all radioactivity comes from the surrounding rock. Readings made underground may be considerably higher or lower than those at the surface.

Mass Effect

A counter reading may be strongly influenced by the size of the sample tested, particularly if it has above-average radioactivity. A large piece of rock gives off more gamma rays than a small piece, and hence different counter readings can be obtained from specimens of different sizes having the same uranium content.

The mass effect can be demonstrated by comparing the reading obtained from a hand specimen, with a reading taken against the rock face from which the hand specimen was taken and with a reading taken with the counter inserted into a crevice within the rock.

Mass effect is most marked with uranium ores and with rocks of above-average radioactivity, such as the granite mentioned above. With rocks of average radioactivity, such as most barren sandstone, little mass effect can be detected, and if cosmic activity is high, a lower reading can be obtained within a rock crevice than with a hand specimen because some cosmic rays are absorbed.

Mass effect is particularly important to the uranium miner because he commonly tests rocks of high radioactivity. Some miners have the impression that a counter which has been checked against a hand sample of known uranium content can be used to directly estimate the grade of an ore pile, it can't!

Thorium Effect (Also Potassium)

In addition to uranium, several other elements are also radioactive, but only two of these - thorium - and radioactive potassium - is sufficiently abundant to create special problems in operating a counter.

Thorium, like uranium, is the parent of a radioactive series which has 11 radioactive members and ends with lead. The gamma activity of the thorium series is about two-fifths that of the uranium series; in other words, rock containing 0.1 percent uranium activates the counter as much as rock with 0.25 percent thorium.

Uranium, thorium and potassium do, however, occur together in igneous rocks, such as granite, and in pegmatite veins which occur in and near granite bodies. Therefore, when prospecting granitic country it should be remembered that some of the measured radioactivity is probably due to thorium, and some may come from potassium. Remember not to forget the value of a chemical assay.

Underground Effect

Mine workings or tunnels present special problems in operating a counter; for example:

1. The instrument is surrounded by rock on all sides and, as a result, the mass effect is intense.

2. Cosmic rays are absorbed by passage through rock and hence their effect is reduced or eliminated in mine workings.

3. Radon contamination may be a problem.

4. In some mines, particularly those which are moist, the rock surfaces are coated with irregular patches of radioactive compounds. These are produced after mining by the action of ground water, which dissolves radioactive salts elsewhere and deposits them by evaporation on exposed rock surfaces and mine faces. Usually these materials are fluorescent under ultraviolet light. Such radioactive coatings constitute only a thin film and do not represent a minable volume of material, but they may be indicative of nearby radioactive minerals.

Background readings in a mine are usually higher than those over similar rocks at the surface, but sometimes the reverse is true.

FLUORESCENCE AND THE ULTRA VIOLET LIGHT

The Ultraviolet Light

The other instrument of use in uranium prospecting is the portable ultraviolet (U.V.) light. Though not nearly as important as the Geiger or scintillation counter, the U.V. light can be quite valuable. Additionally the U.V. light can be used in prospecting for many metals and non-metallic minerals that neither contain uranium or thorium or are radioactive.

The ultraviolet light, often called black light or mineral light is available in two wave lengths. Long wave, which is very similar to the so called "black lights" used to illuminate fluorescent posters, is the lowest energy level ultraviolet light with a wave length in the area of 3,500 A. Shortwave or so called "mineral light" is a higher energy level ultraviolet light with a wave length in the area of 2,500 A. Some fluorescent minerals react to longwave, while nearly all of them and many more react to shortwave. If you must make a choice, it should be shortwave, however, combination lamps are available.

The internal operation of the U.V. light as well as the physical property of fluorescence in minerals is both beyond the scope of this presentation and need be of little interest to the uranium prospector. It is sufficient to know that, as mentioned earlier, five of the common uranium minerals either always in the case of autunite or occassionally in the case of the others are fluorescent, and; some 50 of the rare or trace uranium minerals sometimes are fluorescent.

Fluorescent Uranium Minerals

Fortunately, the majority of uranium's secondary minerals fluoresce in some shade of yellow-green, ranging from deep yellow to bright green, usually better in short wave. They do not phosphoresce. Their dependable glow enables the Geiger operator to move in on a hot formation with the ultra-violet lamp for a close-up by visual inspection.

The important primary uranium minerals, pitchblende and its crystalline counterpart, uraninite, do not fluoresce. Most deposits, however, are accompanied by at least traces of the secondary minerals, formed by alteration of the primary ore. Thus weathering tends to produce fluorescent streaks on outcrops, and percolating ground water carries these tracers with it creating a trail detectable under UV.

The thorium minerals show no visible fluorescence, nor do the rare earths, but there are special U.V. tests for certain of these as well as uraninite and pitchblende.

Autunite, a phosphate, is easily uranium's most brilliant fluorescent mineral. At the approach of the lamp, its brittle micalike flakes spring to life with a yellow-green sparkle recognizable at considerable distance.

Torbernite, also a phosphate, contains copper, a well-known quencher of fluorescence, and is not often fluorescent.

Remove the filter from your lamp and you can pinpoint the torbernite by its strongly intensified emerald-green color. A hand lens may show its thin, flat, typically square plates or flakes.

Uranophane, a silicate, usually shows only a faint yellow-green fluorescence or is nonfluorescent. It is not an important ore, often coating rocks with "paint" or fine, fibrous crystals in minute patterns like flower petals.

Schroeckingerite, a sulfate-carbonate, FL bright yellow-green, occasionally a light bluish green, is very soft and powdery, and dissolves readily in water.

Carnotite, a vanadate and major ore, does not generally fluoresce. It is eyecatching when not too widely disseminated in the sandstone or masked by mineral stains. Remove filter from lamp to make carnotite stand out sharply in contrast to other yellow minerals.

Tyuyamunite, also a vanadate and generally nonfluorescent, has its yellowish color greatly enhanced by rays from the UV lamp with filter removed.

The average uranium-bearing ore you will pick up will probably show its pay mineral as flecks, coatings, or powdery streaks scattered through the matrix.

If your specimen phosphoresces, it is neither uranium nor thorium.

If your fluorescent specimen cannot be scratched with a knife, it is probably not a secondary uranium mineral, most of which can be scratched with the fingernail. Probably instead it is a filling or coating of chalcedony or common opal, both of which will be fluorescent if they contain as little as .000048% uranium.

Chalcedony and common opal, along with petrified wood agatized wood and agatized bone usually exhibit a green fluorescence under short wave U.V.

when they contain trace amounts of uranium and this can sometimes be used as a tracer to deposits.

PROSPECTING

Unlike most valuable minerals, uranium has not been long sought after and prospected for. Uranium prospecting was essentially nonexistent prior to the late 1940's. But, in boom and rush days of the 1950's prospectors with counters were everywhere and most radioactive outcrops were noted.

Start by researching old literature especially that published by the old AEC, and mine files at the Arizona Department of Mineral Resources. Arizona Bureau of Geology and Mineral Technology Bulletin 182 is an excellent over all data source. Establish a region of interest and reevaluate the published data in the field yourself.

When making your ground survey with Geiger or scintillator, mark all hot spots for later U.V. study, or narrow down the hottest area for later study by night or in daytime under a black cloth about two yards square.

Watch for alteration halos-yellowish or rusty rings around a crystal or embedded rock in matrix. If uranium, the halo may fluoresce. If it does not, it may be an alteration product of thorium. Unusual color changes in nearby rocks are sometimes brought about by uranium or thorium content ranging higher than equivalent .01 percent uranium as follows.

Near uranium, quartz is turned smoky, diamond becomes green, coarse calcite assumes a pink color, fluorite turns a deep purple. Green monazite is highly uraniferous, though uraniferous monazite is not always green.

Near thorium minerals, quartz becomes rose-colored. Feldspar has a halo of reddish color around primary uranium or thorium minerals. Radioactive minerals do not cause these always but do so in enough cases to make them useful.

Radiation-damaged zircon crystals sometimes show fluorescent zones, blue or multicolored. Damaged fluorites turn black and evil-smelling; celestite may turn blue, beryl a golden color.

Try to identify the fluorescent tracers, even if they plainly are not uranium. The glow of a lead or zinc mineral, for instance, is an encouraging reminder that lead-zinc ores often are companions of pitchblende.

All interesting spots should be mapped and sampled. Don't make the mistake of not being able to retrace the location of a "hot spot."

The following general suggestions might also prove of value.

1. Reevaluate areas where uranium minerals or anomalous amounts of uranium have already been found.

2. Look for areas of unexplained radioactivity.

3. "Investigate geologically favorable areas for the presence of elements commonly found in varying amounts with uranium, such as vanadium, copper, molybdenum, selenium, and arsenic deposits in sedimentary host rocks; or silver, lead, cobalt, nickel, and copper in vein deposits." Aluminum,

titanium, and ferric iron are especially lacking, and magnetic properties are typically negative.

4. In known uranium-bearing areas, examine extensive sandstone outcrops that are bleached or iron-(limonite-) stained. Drilling may be warranted if geologic conditions are favorable after radioactivity has been detected, even if weakly.

5. Follow known trends rather than testing at random. Large deposits often cluster in elongate trends, which offer better-than-average places to drill, for they may mark the direction in which the ore-forming solutions moved.

6. Investigate the marginal zones of base-metal deposits, which are better places to prospect than the districts themselves.

Inasmuch as 96 percent of the uranium deposits of commercial ore in the United States are in sediments that are continental (formed on land) and clastic (fragmental, broken), the following prospecting suggestions that are specific for these deposits are worth emphasizing:

1. Select a uranium province: this refers to the Rocky Mountains, in which nearly all the uranium of the United States has been mined to date.

2. Find, by regional reconnaissance, an ancient or modern basin, 1,000 to 10,000 square miles in area, that was fed by granite wash not too far from its source and that contains tuff (from volcanic ash) and sandstone that was laid down by streams. Large oil and coal resources are negative, although scattered ones need not be. A positive reading (anomaly),

especially of total gamma radiation, recorded from the air is an added sign of encouragement, and each area has its own set of air guides, which should be listed.

3. Look for the following features:

a. Sandstone or conglomerate:

(1) Thick but not too thick

(2) Interbedded with mudstone beds, lenses, or zones

(3) Carbonaceous: medium content of organic matter - "dirty"

(4) Poorly sorted: of different sizes

(5) Pastel colors: bleached gray, green, buff sandstone, caused by a favorable reducing environment in contrast to red and brown sandstone in an oxidizing environment, which is generally less favorable; the gray versus red color contrast is mostly limited to the Colorado Plateau, except that pink is a good indicator for some deposits of moderate size.

(6) Moderately fractured: permeable enough to have admitted the original solutions but not so permeable as to allow too much leaching away of uranium.

In summary: "continental, fluvioclastic, porous, unconsolidated, carboniferous, arkosic sandstone and conglomerate, "dirty, cherty, trashy, arkosic, mud-seamed sands."

b. Flattening of dipping beds, in the transitional zone between fast-water (sand) and slow-water (silt) deposition.

1-c. Halo of uranium anomaly: chemical, radiometric, or mineralogic.

d. Yellow or black uranium minerals and pyrite

4. Trace to their sources any geochemical patterns in stream water.

About Thorium

Inasmuch as thorium has its principal uses outside the nuclear-energy program, a few words about them are in order. Magnesium alloys consume the largest amount. Thorium chemicals are much employed in making incandescent-gas mantles and have some uses in other products.

Monazite has always been the only important thorium-bearing mineral, although it is a cerium phosphate, (Ca, La, Nd) PO_4, which contains up to 11 percent thorium. Thorianite (oxide) and thorite (silicate) are true thorium compounds but are much less abundant. Monazite is a heavy mineral, reddish brown to yellow; thorianite and thorite are dark gray to black or reddish brown.

LITERATURE

Sources of Literature

Uranium has been the subject of as much or more literature in recent years as any mineral commodity. A tremendous amount has been published by government agencies, in technical journals and as "do-it-yourself" books on prospecting. Much of the literature was published during the early to mid-1950's, the so called "boom" years and is now out of print. The recent (mid-1970's) resurgency of uranium demand and exploration has caused an increase in the amount of literature presently being published.

Many prospecting guides and especially those written on uranium in the 1950's dwell considerably upon mining law and regulations, claim staking procedures, government buying programs and incentives and marketing. However, both government regulations and marketing economics change. The technical staff of Arizona Department of Mineral Resources is always available to discuss the current status of regulations and markets. The uranium prospector is invited to make and keep contact with the Department. Further, every prospector operating in Arizona should have a copy of the Department's Laws and Regulations Governing Mineral Rights in Arizona which explains in detail in everyday language mining laws, regulations and claim staking procedures.

In place of a typical bibliography listing of references at the conclusion of this guide, this chapter will list catagorically a number of publications of potential interest to the independent uranium prospector. The literature will be generally divided into three catagories: (1) location of known occurrences, (2) geology and (3) prospecting.

Uranium Occurrences

Available (both in print and out of print but in libraries) information on uranium occurrences in Arizona exist generally in four forms: (1) individual mine file data at the Arizona Department of Mineral Resources in Phoenix, (2) the uranium chapter in Mineral and Water Resources of Arizona, published by the Arizona Bureau of Geology and Mineral Technology in Tucson as Bulletin 180, (3) the uranium section in Coal, Oil, Natural Gas, Helium and Uranium in Arizona also published by the Arizona Bureau of Geology and Mineral Technology in Tucson as Bulletin 182, and (4) the U.S. Atomic Energy Commission (now Department of Energy) series of Preliminary Reconnaissance Reports on the various Arizona counties. All of the above items are available for reference at the Arizona Department of Mineral Resources office in Phoenix. Items 2 and 3 are currently (1978) for sale by the Arizona Bureau of Geology and Mineral Technology, Publications Office, 845 North Park Avenue, Tucson, Arizona, 85719 (Item 2 - $4.50; Item 3 - $4.50 plus 10% postage and handling.

A partial bibliographic listing of literature on uranium occurrences in Arizona follows:

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U.S. Atomic Energy Commission, (Mid 1950's); Mohave County Uranium Deposits Preliminary Reconnaissance Atomic Energy Report; U.S. Atomic Energy Commission, PB 172 - 485, 169 p.

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Uranium Geology

A partial bibliographic listing of literature on the geology of uranium deposits follows. Listings are generally restricted to those of potential value to the prospector.

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Prospecting

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By MIKE McCLOY
Associated Press Writer

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2

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Ralph C. Kirby and James A. Barclay, US Bureau of Mines

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Table 8—Copper Ore—1,650,000 TPY;

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Economic Evaluation o cesses." *Min. Cong. J.* January 1975, pp.