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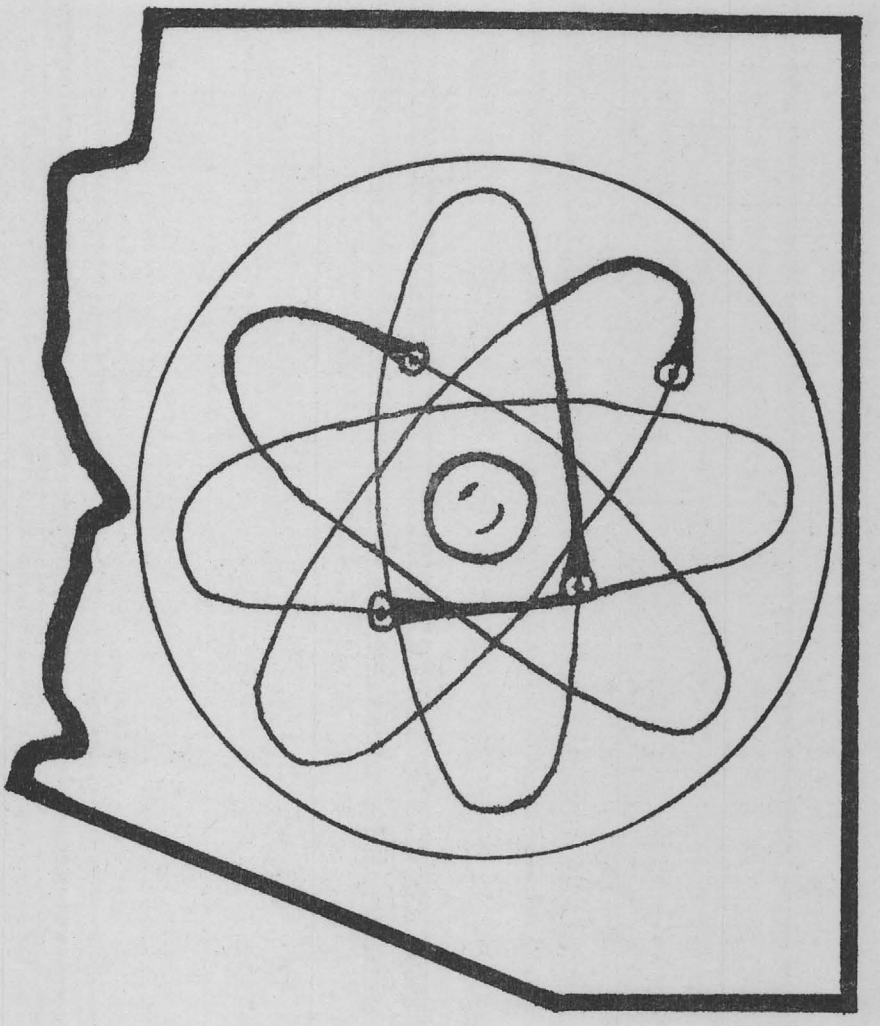
URANIUM
A PROSPECTOR'S GUIDE

SPECIAL REPORT NO. 1



BY

KEN A. PHILLIPS

AND

MICHAEL N. GREELEY

ARIZONA DEPARTMENT OF MINERAL RESOURCES

Special Report No. 1

URANIUM

A PROSPECTOR'S GUIDE

by

Ken A. Phillips
Mineral Resources Engineer

and

Michael N. Greeley
Field Engineer

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STATE OF ARIZONA

DEPARTMENT OF MINERAL RESOURCES

John H. Jett, Director

Phoenix Office:

Mineral Building, Fairgrounds
Phoenix, Arizona
85007
Phone: (602) 255-3791

Tucson Office:

State Office Building
Room 208, 415 W. Congress
Tucson, Arizona 85701
Phone: (602) 882-5399

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A PROSPECTOR'S GUIDE

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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.)

A partial bibliographic listing of literature on uranium occurrences in Arizona 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.