COLORADO DEPARTMENT OF NATURAL RESOURCES

ROCK TALK

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Uranium—It's Hot!! And Back by Popular Demand

Pure elemental uranium is a slightly radioactive metal, silvery white in color and dense (almost as dense as gold). Elemental uranium metal does not occur in nature because it readily combines with oxygen to form several uranium oxide minerals and compounds. The most significant property of uranium is that it is the "parent" element in a radioactive decay series that eventually leads to formation of a particular isotope of lead. Radioactive decay means that certain elements, such as uranium, will over a specific period of time, give off atomic particles—electrons, protons, and neutrons—leading to changes in the atomic weight and number of the parent element. This decay is a natural constant in that half of a given amount of uranium-238 (^{238}U—the 238 superscript refers to the atomic weight of the atom) will decay to lead in about 4.5 billion years. It does not decay directly to lead but passes through several daughter elements including thorium, radium, radon (a gas), and bismuth on its path to a stable isotope of lead. See Figure 1 for a much-simplified chart of the uranium-lead radioactive decay series.

Burro No. 7 Mine, Slick Rock, Colorado. (Photograph by Jim Cappa, 2005)

Uranium is found in nature in three main isotopes. ^{238}U is the most common constituting about 99.3 percent of all natural uranium; ^{235}U constitutes about 0.7 percent of all uranium; and other isotopes such as ^{234}U form trace amounts. ^{235}U is important because it is readily split as part of the fission process (Fig. 2) and in the process releases substantial energy. ^{235}U is more radioactive than ^{238}U because of its shorter half-life, about 700 million years, and as such, the ratio of ^{238}U to ^{235}U has changed over geological time. In the earth's past, there was a higher percentage of ^{235}U than today. Scientists believe that this higher percentage of ^{235}U (about 3 percent) led to a natural nuclear fission event that occurred about 1.7 billion years ago in present-day western Africa.

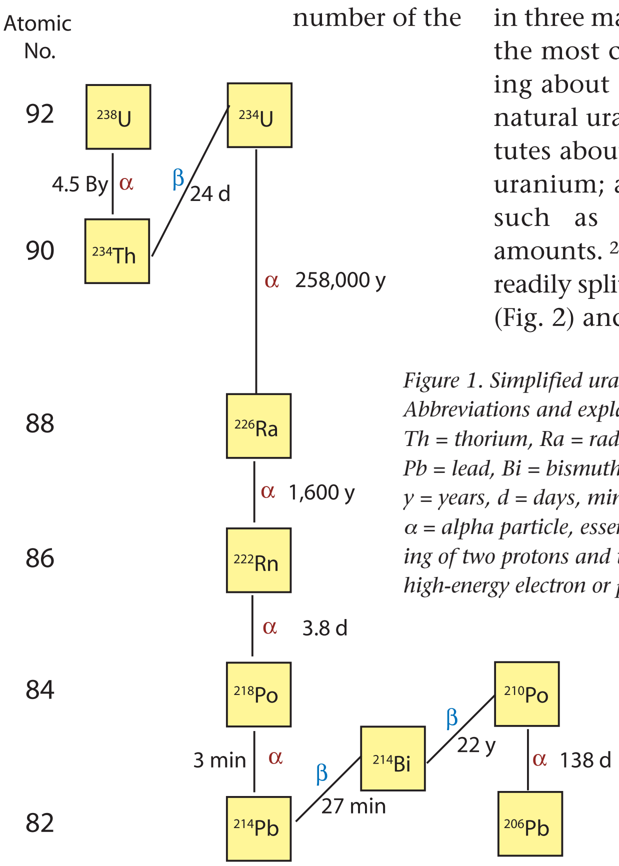

Figure 1. Simplified uranium-lead radioactive decay series. Abbreviations and explanation: Elements: U = uranium, Th = thorium, Ra = radium, Rn = radon, Po = polonium, Pb = lead, Bi = bismuth. Half-lives: By = billion years, y = years, d = days, min = minutes. Subatomic particles; α = alpha particle, essentially y a helium nucleus consisting of two protons and two neutrons. β = beta particle a high-energy electron or positron.

Inside this issue: The Discovery of Uranium, its Uses and Future, the History of Uranium Mining in Colorado, Geology of Uranium Deposits in Colorado, Cleanup of Contaminated Mill Sites, and other useful information about Uranium

From the Division Director—

The boom is back! Colorado, which has supplied uranium to the world for more than a century, is seeing the return of interest in this important energy resource. Prospectors are dusting off their scintillometers and heading for the hills. Their apparent success is indicated by the filing of 3,000 new mining claims in the state last year.

Why the boom? Currently, the 435 nuclear reactors in the world need 180 million pounds of uranium per year, but the world only produces 110 million pounds. The shortfall has been made up by depleting stockpiles from the last boom cycle and by conversion of nuclear weapons. Both are diminishing in supply and consequently the price of uranium increased from $10 per pound in 2003 to more than $55 per pound today.

China and India's increase in the use of nuclear energy increases the demand for uranium. However, the United States also needs a lot of uranium because we are the world's leading producer of nuclear energy. Indeed, we produce more nuclear energy than France, Spain, Germany, Sweden, and the United Kingdom *combined*.

One of the best kept secrets in our country is that U.S. production of electricity from nuclear plants has increased over the decade since the last nuclear power plant came on line in 1996 (it was ordered in the early 1970s). This was achieved by increasing the operating efficiency of the plants. Today we produce nearly twice as much nuclear power as any other country in the world, an amount equal to 30 percent of the world's nuclear energy.

The increase in interest in uranium is but an indicator of growing interest in all of Colorado's rich natural resources. China and India's appetite for natural resources creates worldwide shortages and drives up prices of nearly every energy and mineral commodity. Colorado communities are already suffering from China-caused shortages of steel and cement. Prices for such diverse commodities as gold, copper, aluminum, molybdenum, chromium, titanium, selenium, and antimony have skyrocketed in the 21st century with percentage price increases ranging from a low of 48 percent to more than 1,700 percent! As shortages grow and prices increase, Colorado can expect to see increasing pressure to develop our rich array of energy and mineral resources.

Vince Matthews

A Natural Nuclear Reaction in Africa 1.7 Billion Years Ago

In the early 1970s, scientists noted that something was strange about the uranium ore being mined at the Oklo deposit in Gabon, West Africa. The ore was depleted in the fissionable isotope of uranium, ^{235}U, and resembled the percentage found in spent nuclear fuel-about 0.25–0.30 percent (it should have been 0.7 percent). At the time, this uranium deposit was formed (about 2,000 million years ago) the percentage of ^{235}U was close to 3 percent, about the same as what is used in a modern nuclear reactor. Scientists think that water seeped into the deposit at about 1.7 billion years ago and allowed the neutrons emitted from uranium to slow enough to initiate a chain reaction, which then over time heated the water into steam causing the chain reaction to cease. This process may have happened numerous times until the amount of ^{235}U was depleted enough to cause the cessation of the chain reaction.

The products of the nuclear reaction remained within the Oklo deposit and were never dissolved or spread by ground water for 1.7 billion years. This fact gives scientists hope that nuclear waste stored in geological formations may be immobile for, at least, millions of years.

Discovery of Uranium and Radioactivity

In 1789, uranium oxide was first recognized as the mineral pitchblende (now considered as a variety of uraninite). The mineral was recovered from a silver mine in Joachimsthal, Bohemia, now a part of the Czech Republic, by an amateur chemist, Martin Klaproth. Klaproth named the compound uranium in a tribute to his friend, William Herschel, a famous composer and astronomer, who had discovered the planet Uranus (Uranus is the Greek god of the Heavens). However, it was not until 1841 that the true metal, uranium, was isolated from its oxide form by a French chemist, Eugene Peligot. In 1896, another French scientist, Henri Bequerel, left some uranium in a drawer with a photographic plate for a few days and to his surprise found the photographic plate to be exposed. This lucky "experiment" was the beginning of atomic research and the understanding of radioactivity.

Marie Curie and her husband Pierre conducted various experiments on uranium ore, some of which came from Colorado, from 1898 through the 1920s in their lab in Paris. They recognized the process of radioactivity and discovered two of uranium's daughter products, polonium and radium. In the 1930s and early 1940s, scientists discovered that one isotope of uranium, ^{235}U, was fissionable—that is when an atom of ^{235}U is bombarded by neutrons its nucleus splits into two equal parts, usually an atom of barium and krypton, at the same time releasing substantial energy in the form of heat and two or several more neutrons (Fig. 2). The released neutrons then collide with other atoms of ^{235}U, releasing more energy and neutrons, a process known as a chain reaction. The chain reaction released such large amounts of energy that it led to the development of nuclear weapons, ending World War II. After the end of the war scientists put the energy released by fission to work to heat water, create steam, turn a turbine to generate electricity—the major use of uranium today.

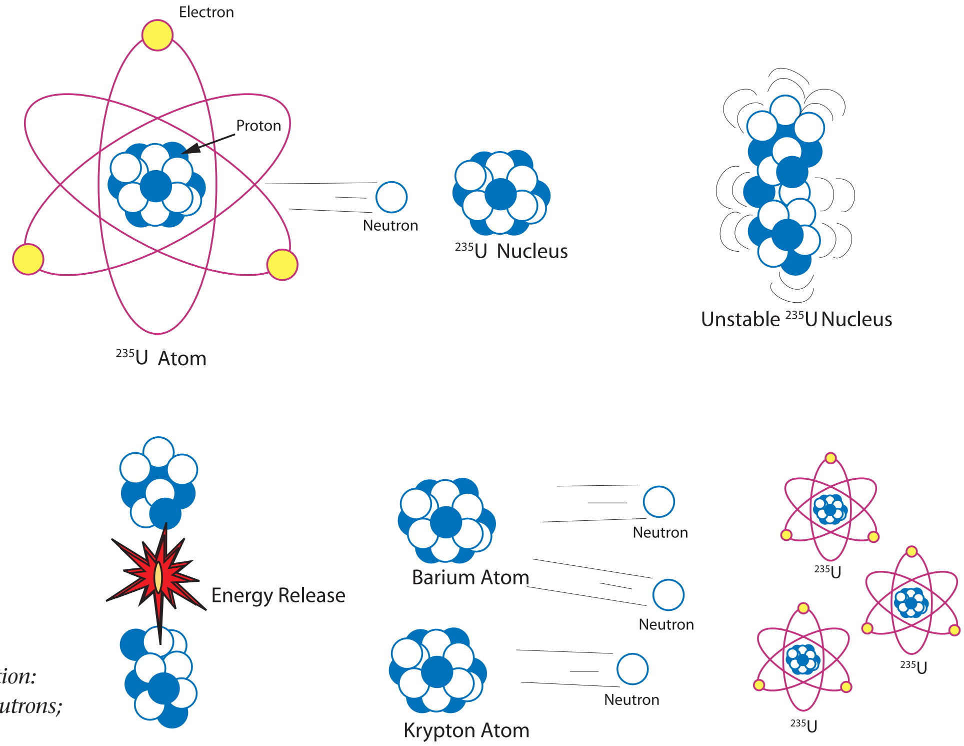

Figure 2. Atomic fission of uranium. Explanation: Solid blue circles = protons, White circles = neutrons; Yellow circles = electrons.

Uses of Uranium

The very first uses of uranium, mostly in the form of complex uranium oxides, were as an agent in glass manufacture. A small amount of uranium was added to the glass giving yellow and green colors to the finished product. The glass is called Vaseline glass because it resembles the color of Vaseline (Fig. 3). Uranium oxide minerals, because of their bright yellow colors, were probably used as ornamentation paints by aboriginal tribes in North America and other localities. The uranium colored glass fell out of favor in the 1920s; however, one American manufacturer used uranium oxide to color its popular "Fiestaware" dinner plates a brilliant orange-red color as late as 1940.

The work of Pierre and Madam Curie demonstrated that radium was a daughter product of uranium and that small amounts of radium could be recovered from uranium mineral deposits. In the early 1900s, it was thought that radium was a cure for cancer and other ailments. Hot springs and spas advertised themselves as "radium springs," whether they had radium in them or not. Various drinks and ointments were made from radium; again, the manufacturers espoused their curative effects. Radium was also being used to paint luminous dials on clocks, watches, altimeters, and other instruments. Young girls were hired to paint the radium on the dial faces and they were instructed to point their paintbrushes with their lips. Many of the young women contracted radiation poisoning and a number of them died in the 1920s and 1930s. A famous court case in which five "Radium Girls" sued U.S. Radium Corporation was settled in 1928 and exposed the deadly effects of radium. Its use declined drastically after that.

Figure 3. Erich and Ida Martin piece from Sixth Annual Vaseline Glass Collectors Inc. 2004 Convention. (http://www.vaselineglass.org/)

In the 1930s, scientists came to understand the nature of radioactivity and the atomic nuclear fission process as having the potential of releasing large amounts of energy. After World War II began in late 1941, the United States government began a research project at Los Alamos, New Mexico to develop an atomic weapon, which resulted in the production of three atomic bombs, one that was tested in southern New Mexico and two that were dropped on the cities of Hiroshima and Nagasaki, Japan in August 1945, effectively ending World War II. Uranium production continued in the United States, Canada, and other places during the Cold War years following the end of the World War II. Almost all of this uranium went into the production of nuclear weapons.

Uses of uranium changed in the 1950s with the 1954 launch of the USS Nautilus, the first ship to be powered by

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a nuclear reactor. The Nautilus is a submarine and it made headlines because of its ability to remain submerged for long periods powered by its nuclear reactor. The first nuclear reactors designed for the generation of electricity went into production in the 1950s. As the 1960s ended and the 1970s began, the use of uranium as fuel for reactors to create electricity grew. Today, the primary use of uranium is to provide fuel for nuclear reactors that produce electricity; although it is still used for weapons manufacture.

Today, there are 103 operating nuclear power plant reactors in the United States, which generate about 20 percent of the United States' electrical power demand. This is more than double the amount of the next largest generator, Japan. France, which has the highest percentage of electricity generated by nuclear power—78 percent, boasts only 59 nuclear power plants. No new nuclear power reactors have been built in the United States since construction commenced on the Riverbend reactor in Louisiana in 1977. In spite of this, nuclear power production has been steadily increasing, mostly because reactors have increased their efficiency (Fig. 4). Nuclear power plants provide low cost electricity and have essentially no greenhouse gas emissions. However, technical and political issues on nuclear waste disposal and nuclear plant decommissioning are ongoing concerns.

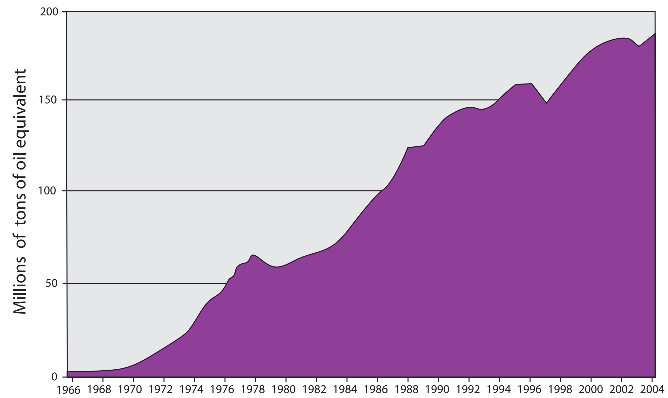

Figure 4. Nuclear energy consumption in the United States. (From Energy Information Administration—U.S. Department of Energy)

What is enriched uranium, and depleted uranium?

In order to make a nuclear reaction occur there has to be a greater percentage of the more fissionable ^{235}U in the fuel than occurs in nature. The enrichment process converts U_3O_8 into a gas, uranium hexafluoride (UF_6), which enables the uranium to be enriched from a ^{235}U content of 0.7 percent to about three to four percent. The enriched UF_6 is converted back into UO_2 and formed into fuel pellets. So-called weapons grade uranium is enriched to much higher levels of ^{235}U, generally greater than 90 percent.

Depleted uranium is created by the process of making enriched uranium and contains 0.25 to 0.30 percent ^{235}U. Every ton of natural uranium enriched for nuclear energy purposes contains about 260 pounds of enriched uranium and the remaining 1,740 pounds is depleted uranium. Depleted uranium is very dense (about 1.7 times lead) and is used as counterweights in aircraft, keels of boats, and as military projectiles.

History of Uranium Prospecting and Mining in Colorado—a Story of Boom and Bust

Uraninite, the black oxide mineral of uranium (UO_2) was first discovered in the United States in 1871 within gold and quartz veins at the Wood Mine near Central City, Gilpin County, Colorado. Minor production of uranium occurred through the late 19th Century from these mines.

In 1881, a yellow uranium oxide mineral was discovered in southwestern Colorado on Roc Creek in Montrose Country. This was the first discovery in what would become the highly productive Uravan mining district. It was not until 1898, that this new mineral was named carnotite after the French mineralogist Adolphe Carnot. Some of the ore from Roc Creek was sent to Madam and Pierre Curie in Paris for their early investigations into the properties of uranium and radioactivity.

Colorado experienced four periods of uranium and associated minerals boom and bust cycles.

1. Radium boom of the 1910s
2. Vanadium boom of the 1930s–40s (the uranium ores of southwestern Colorado are very rich in vanadium).
3. Uranium boom of the 1940s—related to weapons manufacture
4. Uranium energy boom of the 1950–70s, decline from the late 70s to 90s, and the uranium resurgence starting in 2003.

Radium Boom

Uranium ores in Colorado were not developed until the early 20th Century after the Curies announced the supposed beneficial uses of radium. Prospectors realized that the carnotite ores of southwestern Colorado were easily mineable and contained radium. The amount of radium in the typical carnotite ores of the Uravan district is very small. It took about 200–300 tons of high grade (about 2 percent U_3O_8) carnotite ore to produce one gram of radium. However, during this period radium was selling for $160,000 to $120,000 per gram (31 grams = one ounce) making the mining of these ores a very profitable operation. The radium boom got underway in 1910 when the Standard Chemical Company started producing radium and vanadium at the Joe Dandy property in Paradox Valley south of Uravan. Other mining and processing operations supported by the U.S. Bureau of Mines and the National Radium Institute commenced

Uranium Minerals

- Uraninite (pitchblende): UO_2, often containing thorium, lead, and other metals of the lanthanum and yttrium group. Uraninite is very dense, black to brown, has a greasy luster, and is radioactive. It commonly occurs with coffinite in the Uravan district.
- Coffinite: $U(SiO_4)_{1-x}(OH)_{4x}$, a black hydrated aluminum silicate is named after R.C. Coffin, a Colorado Geological Survey geologist who wrote the one of the first monographs on the Uravan district (Coffin, 1921).
- Carnotite: $K_2(UO_2)_2(VO_4)_2{\cdot}3H_20$, a secondary mineral of uranium with a bright yellow color.
- Autunite: $Ca(UO_2)_2(PO_4)_2{\cdot}10–12H_20$, a common secondary mineral after uraninite. It has a yellow to yellow-green color and a prominent yellow-green fluorescence.
- Tyuyamunite: $Ca(UO_2)_2(VO_4)_2{\cdot}5–8H_20$, similar to carnotite with Ca substituting for K. Often associated with carnotite and very similar in appearance.

in Long Valley (Fig. 5). In 1913, Standard Chemical Company built the Joe Junior radium processing plant and town site on the San Miguel River at what would later grow into Uravan. Later the Radium Company of Colorado (Fig. 6) or its contractors utilized several radium processing plants in Denver. The Environmental Protection Agency recognized the hazard posed by these old radium processing sites, and in the 1980s began an ongoing cleanup of the contaminated sites.

The Colorado radium business received a shock in 1921 when very high-grade uranium ores (up to 60 percent U_3O_8) were found and developed at the Shinkolobwe deposit in the Belgian Congo (present day Democratic Republic of the Congo). The Belgians lowered the price of radium to $70,000 per gram and the Colorado radium mines could not compete and were shut down. From 1898 to 1923, the mines of southwestern Colorado and Rifle produced an estimated 67,000 tons of carnotite ore, which resulted in the production of 202 grams of radium (454 grams/ pound) at an average price of $120,000 per gram resulting in a value of $24.2 million—$265 million in 2005 dollars (Amundsen, 2002).

Vanadium Boom

In the mid 1910s, the world was gradually moving towards World War I and vanadium was beginning to be used to harden steel, especially in cannons and other weaponry. The carnotite ores of southwestern Colorado and the area around Rifle, Colorado contain significant amounts of vanadium. In 1916, Standard Chemical Company added a vanadium circuit to the Joe Junior plant

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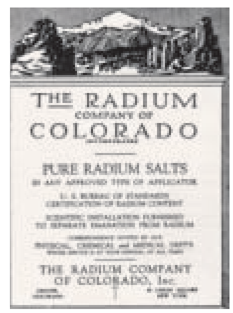

Figure 6. Advertisement from the Radium Company of Colorado

Figure 5. Long Park 16 Mine, near the site of the Radium Institute processing plant. (Photograph by Jim Cappa, 2005)

Figure 7. United States Vanadium Company plant, Uravan, in the late 1930s or early 1940s. Photograph courtesy of the Colorado Historical Society, CHSX 6203. (Photograph by Bob Zellars)

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and began producing vanadium. After the radium bust of 1921, the mines of southwestern Colorado continued to produce vanadium for steel hardening. Vanadium Corporation of America gained control of the radium mines and plants and United States Vanadium Company expanded the Joe Junior site and named it Uravan after the combination of uranium and vanadium minerals. Throughout the 1930s and 1940s, production of vanadium brought some prosperity to Uravan and all of southwestern Colorado (Fig. 7).

Prior to 1937 the uranium in the carnotite ores of southwest Colorado was considered a contaminant and ended up in the mine and mill waste piles. Unites States Vanadium Company installed a uranium recovery circuit in their mill in 1937 and used the uranium, just like the vanadium, as a steel hardener. Vanadium was a strategic mineral and a government-buying program encouraged continued exploration and development.

Pre-1946 production of vanadium from Uravan and the surrounding districts was 636,166 tons at a weighted average grade of 1.9 percent V_2O_5 resulting in the production of 24,138, 822 pounds of V_2O_5 (Chenoweth, 1981).

Uranium in Weapons Boom

United States entry into World War II in December 1941 changed the picture in the Uravan district dramatically. The government realized that in order to win this war they needed a superior weapon. The nuclear fission process was barely understood when the government initiated the Manhattan Project, the goal of which was to develop an atomic bomb. The Manhattan Engineers District, part of the project focused on acquiring uranium, purchased all the uranium-rich waste piles from the Uravan mineral belt mines and mills and contracted with United States Vanadium Company to process the ores for uranium. Uravan became a bustling, busy place with many new workers, homes, schools and all the amenities of a regular community.

Most of the uranium that was acquired by the Manhattan Project came from the Shinkolobwe Mine in the Congo (approximately 4,150 tons), and to a lesser extent the Port Radium Mine in Canada (1,000 tons), and the Uravan district (850 tons) (Amundsen, 2002). World War II ended with the dropping of two atomic bombs produced by the Manhattan Project on Hiroshima and Nagasaki, Japan in August 1945. Production of uranium at Uravan ceased for a short while. The total production from the United States Vanadium Company mill at Uravan to late 1945 was 1,782,000 pounds of U_3O_8 (Goodknight and others, 2005). In 1947, the newly created Atomic Energy Commission (AEC) contracted with United States Vanadium Company, which was bought by Union Carbide Nuclear Corporation in 1955 (Fig.8) to produce uranium for the Cold War effort. The AEC ended its uranium contract in December 1970. From 1947 to 1970, the mill at Uravan produced 23.9 million pounds of U_3O_8 (commonly referred to as "yellowcake") and 9.7 million pounds of V_2O_5 for the AEC. An additional 123.4 million pounds of V_2O_5 was sold on the open market to the steel industry.

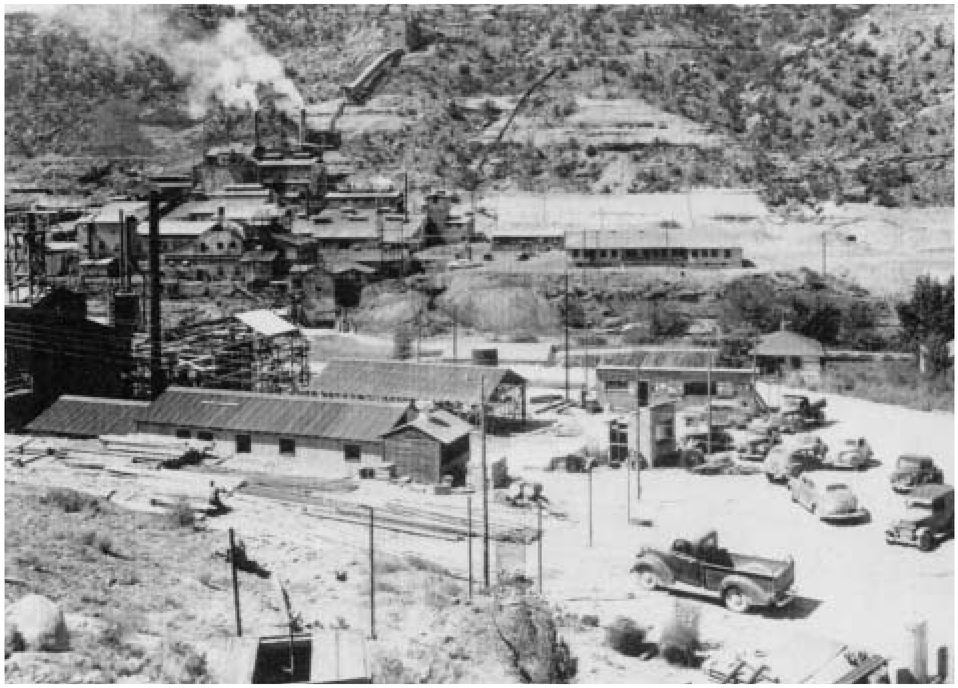

Figure 8. Manhattan District uranium mill site, Uravan, 1944. (Estalee Silver Collection, downloaded January 15, 2006 from www.uravan.com)

Uranium Energy Boom and New Discoveries

Prospecting for uranium deposits continued throughout the 1950s and 1960s, resulting in limited production from the Central City district in the Front Range, and other localities throughout the state. In Colorado, the largest single uranium deposit in Colorado was discovered along Ralston Creek in Jefferson County in the late 1940s. Fred Schwartzwalder had leased for the property for its copper potential and had taken some samples to his home. Later he ran a Geiger counter over the samples and found them to be radioactive. It took Fred some time to locate the exact spot where he had taken the sample, but he eventually did. The Schwartzwalder Mine began production in 1953 and had a total production of 17 million pounds of uranium oxide at an average grade of 0.48 percent U_3O_8 before its closure in March 2000 (Fig. 9).

Figure 9. Schwartzwalder Mine, 1993. (Photograph courtesy of Jim Paschis)

Uranium deposits occur in Upper Paleozoic carbonate rocks along a prominent north-trending fault at the Pitch deposit in Saguache County. The deposit was developed by two adits from 1959 through 1962 and produced about 100,000 tons of uranium ore at an average grade of 0.50 percent U_3O_8, equivalent to one million pounds of U_3O_8. In 1972, Homestake Mining Company acquired the property and proceeded to develop an open pit-mineable resource of 2.1 million tons at an average grade of 0.17 percent U_3O_8, equivalent to 7,140,000 pounds of U_3O_8. Homestake mined the deposit from 1975 to 1985, and the ore was processed at Homestake's mill near Grants, New Mexico.

The Cochetopa uranium district is located in northwestern Saguache County about 20 miles southeast of Gunnison. The original discovery of the district was made in 1954 at the Los Ochos claim, which eventually became the Thornburg Mine. As in the Uravan district the Upper Jurassic Morrison Formation is the host rock of the uranium ore. The Thornburg Mine produced over 1,253,000 pounds of U_3O_8 at an average grade of 0.14 percent (Nelson Moore and others, 1978).

Uranium in the form of the mineral autunite was discovered in the volcaniclastic rocks of the Tallahassee Creek

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district, Fremont County in the 1950s. Mining commenced from several small mines in the district and by the late 1960s, about 440,000 pounds of U_3O_8 had been produced. In the 1970s, the Hansen Creek deposit was developed by Cyprus Mines Corporation; it contains significant uranium, over 25 million pounds, albeit at a low grade of 0.08 percent U_3O_8 (Dickinson, 1981). The deposit was never mined because uranium prices tumbled in the 1980s

The Uravan district began a new expansion to serve the growing needs of the nuclear power industry. In 1976, the mill was expanded to process 1,300 tons per day. However, the declining demand for nuclear power, the low prices for uranium and the increasing supply from Canada, Australia, and other countries spelled out the eventual decline of the long-lived town of Uravan and the surrounding mines and mills of the Uravan mineral belt. In 1984, the Uravan mill was closed and the town was abandoned. Cleanup activities commenced and continued through the spring of 2006 (Fig. 10). Approximately 84 million pounds of uranium oxide and 220 million pounds of vanadium oxide were produced from the Uravan district from 1936 to 1984.

Because of the end of the Cold War and the release of uranium from weapons stockpiles, the recession of the 1980s, and other factors, the price of uranium slipped from its high of $40 per pound in the late 1970s to prices below $10 per pound for most of the 1980s and 1990s. As uranium stockpiles dwindled and worldwide economies improved, the demand for uranium increased and, of course, the price began to climb somewhat dramatically in 2003 (Fig.11). The worldwide demand for uranium is 180 million pounds per year to feed 435 nuclear reactors; however, worldwide mine production in 2005 was only 110 million pounds. Demand for uranium will increase as China plans to build 27 new reactors in the next 15 years and India plans to build 17 in the next 7 years.

With rising uranium and vanadium prices, Cotter Corporation reopened four

Figure 10. The Uravan site in Spring 2005; cleanup work is almost complete. Compare this photograph to Figure 7; both were taken from approximately the same point.

uranium mines in the Uravan district in 2003 and 2004. Cotter was transporting the ore from these mines to their mill in Cañon City for processing. Cotter closed the mines abruptly in November 2005 citing increased costs making these operations unprofitable at this time. The Cotter mines produced 394,236 pounds of uranium oxide and 1,746,251 pounds of vanadium oxide from 2003 through 2005. In July 2006, International Uranium Corp. announced that they plan on reopening four uranium mines in the Uravan district. Three of those mines will be in Colorado; the other will be in Utah.

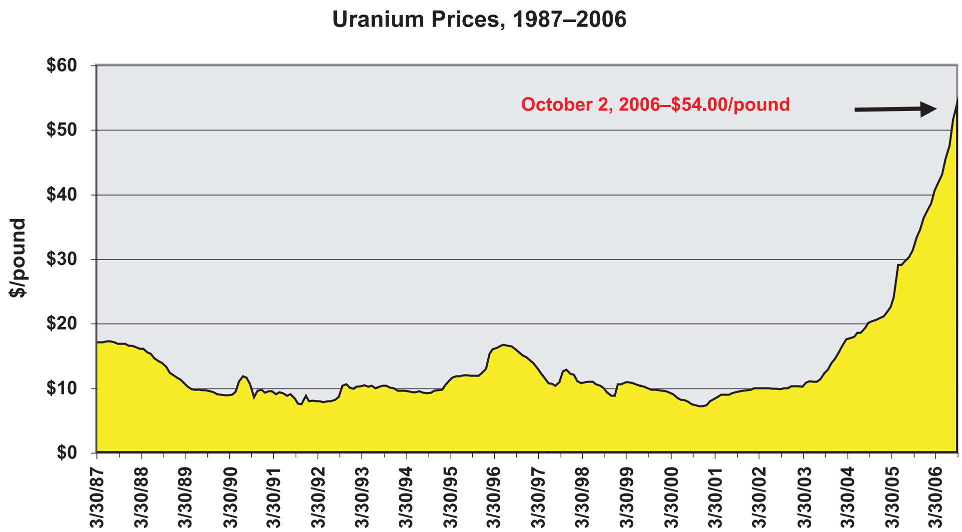

Figure 11. Uranium prices. (Source: Ux Consulting Company, http://www.uxc.com/)

Geology of Uranium Deposits in Colorado

Uranium is a widespread and ubiquitous element. It has a crustal abundance of 2.8 parts per million, slightly more than tin. Primary deposits of uranium tend to concentrate in granitic or alkalic volcanic rocks, hydrothermal veins, marine black shales, and early Precambrian age placer deposits. Secondary (or epigenetic) deposits of uranium are formed later than the surrounding rocks that host the mineral deposit. Uranium is soluble in oxidizing aqueous solutions, especially the U^{+6} valence state, and can be redistributed from primary source rocks into porous sedimentary rocks and structures by groundwater and form secondary (epigenetic) uranium mineral deposits.

Epigenetic deposits of uranium in sedimentary rocks form the bulk of uranium deposits in Colorado. These include the many mines of the Uravan, Cochetopa, Maybell, and Rifle districts, and other scattered places including the Front Range and Denver Basin. Primary uranium deposits in Colorado occur in hydrothermal veins, especially in the Front Range.

Epigenetic Uranium Deposits in Colorado

Epigenetic uranium deposits in the sandstones of the Salt Wash Member of the Jurassic-age Morrison Formation are widespread in the Uravan district of southwestern Colorado. The sandstones of the Salt Wash Member were deposited by meandering streams and were later covered by shales, siltstones, and volcanic ash beds of the Brushy Basin Member of the Morrison Formation. Later, near shore marine sands of the Dakota Formation and marine muds, silts, and sands of the Mancos Shale covered the rocks of the Morrison Formation. The Salt Wash sandstones are porous, permeable, and locally contain abundant fossil plant material. Sometime after the deposition of the sandstones, uranium-

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Figure 12. A uranium roll in the Salt Wash Member, Spring Creek Mesa Mine. Hammer for scale. Dark colored material is uraninite. (Photograph by Jim Cappa, 2005)

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and vanadium-bearing waters, probably derived from the overlying volcanic ash beds, flowed through the sandstones. The uranium- and vanadium-bearing water met changing physicochemical conditions, such as a reducing zone occupied by fossil organic material or changes in the acidity of the water, and the uranium precipitated as the minerals uraninite or coffinite and vanadium precipitated with clay minerals. Uranium and vanadium minerals formed irregularly shaped ore deposits, commonly referred to as uranium rolls. Typical roll deposits from the Spring Creek Mesa Mine near Uravan are shown in Figure 12. Ore deposits in the Uravan district range in size from a few tons to over a million tons. The average uranium grade is about 0.25 percent and the average vanadium grade is about 2 percent.

The Cochetopa uranium district also contains uranium mineralization in the Upper Jurassic Morrison Formation. In the Thornburg Mine, the silicified and brecciated sandstone and mudstone of the Brushy Basin Member of the Morrison Formation contain black, sooty, fine-grained uraninite in veinlets and as finely disseminated grains.

Not all epigenetic uranium deposits in Colorado are located in the much-favored Morrison Formation. The Jurassic-age Entrada and Navajo sandstones in the Rifle Creek district, Garfield County host typical vanadium-uranium minerals. The grade of these deposits ranges from 1 to 3 percent V_2O_5, and generally less than 0.10 percent U_3O_8.

Epigenetic uranium deposits also occur in carbonate rocks in the Marshall Pass district, Saguache County. In the 1970s, Homestake Mining Company geologists working on the Pitch Mine recognized that they had discovered a previously unrecognized type of uranium ore deposit in brecciated dolomite of the Mississippian-age Leadville Limestone. Most of the uranium deposits and prospects of the district occur along the north-trending Chester fault. Large uranium deposits were formed where the fault intersected the Leadville Limestone. Ore mined from 1959 to 1963 was probably also from the Leadville Limestone though the host rock was unrecognized.

Uranium ore in the Tallahassee Creek district occurs in two early Oligocene-late Eocene age formations, the Tallahassee Creek Conglomerate and the Echo Park Alluvium. The Echo Park Alluvium consists of sandstone, shale, and conglomerate. The Wall Mountain Tuff, a rhyolite ash flow tuff, overlies the Echo Park Alluvium. The Tallahassee Creek Conglomerate overlies the Wall Mountain Tuff and is mostly composed of boulders derived from the erosion of volcanic rocks and Precambrian igneous and metamorphic rocks. Uranium was dissolved from the Wall Mountain Tuff by groundwater leaching and then deposited as uraninite in favorable zones in the Echo Park Alluvium and Tallahassee Creek Conglomerate (Dickinson, 1981).

Hydrothermal vein deposits

Vein deposits containing uranium minerals are widespread throughout the Precambrian terrain of Colorado. The central Front Range contains numerous uranium occurrences; most of which were not very productive. However, the largest and most productive uranium mine in Colorado was the hydrothermal vein deposit at the Schwartzwalder Mine located in the Ralston Buttes district of Jefferson County.

The hydrothermal veins of the Schwartzwalder Mine are hosted in Precambrian age metamorphic rocks, schists, gneisses, and quartzite. Most of the uranium-bearing veins are located in garnet biotite gneiss and quartzite. The veins fill north- to northwest-trending, mostly steeply dipping, Laramide-age (about 70 million years ago) fractures in the garnet biotite gneiss, quartzite, and other rocks (Fig. 13). The ore minerals in the veins consist of uraninite (variety pitchblende), some coffinite, copper sulfides, and other base metal sulfides. Quartz and carbonate minerals form the gangue (non-ore) minerals.

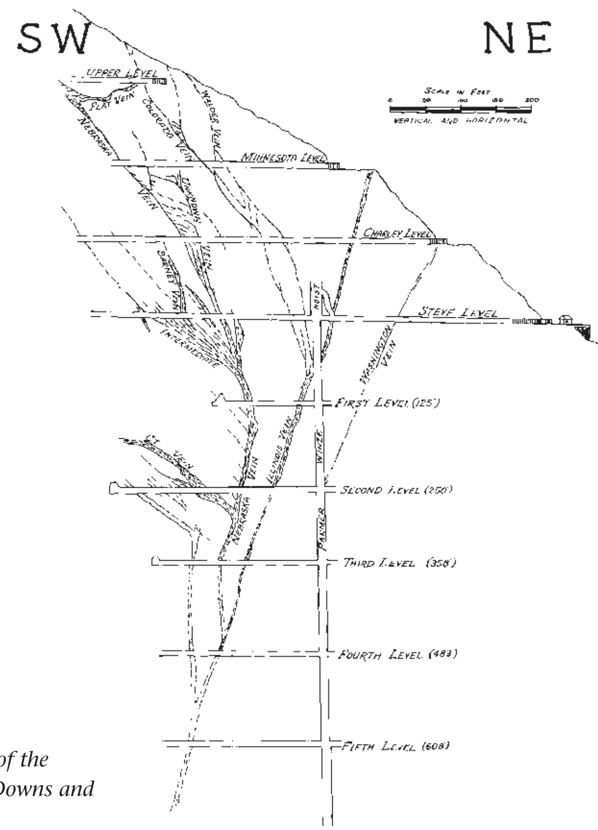

Figure 13. Cross section of the Schwartzwalder Mine. (Downs and Bird, 1965)

Cleanup of Contaminated Uranium Mill Sites

Several uranium mills and processing facilities were built during the boom years of uranium mining in Colorado and later abandoned. All of these facilities had waste piles of spent uranium mill tailings that, in some cases, were used as construction materials for residences, roads, and other buildings. In the 1960s, the Colorado Department of Health (now named the Colorado Department of Public Health and Environment—CDPHE) and the U.S. Public Health Service determined that the tailings in the Grand Junction area posed a significant health hazard and had to be mitigated. At this time, several thousand tons of uranium mill tailings from the Climax Mill in Grand Junction had been used in construction materials. In 1972, the U.S. Congress created the Grand Junction Remedial Action Plan and during the 15-year program, 594 buildings in the Grand Junction area underwent some type of remedial action. The U.S. Congress soon came to realize that the uranium mill tailings hazards were not restricted to the Grand Junction area and passed the Uranium Mill Tailings Radiation Control Act which set up a protocol and funding to clean up uranium mill tailings throughout the U.S.

Cleanup of the nine uranium mill sites in Colorado authorized by the Uranium Mill Tailings Remedial Action program (UMTRA) has been completed. The communities in Western Colorado where uranium mill tailings were cleaned up are: Durango, Grand Junction (including Fruita and Palisade), Gunnison, Maybell, Naturita, and Rifle. Final authorization for the surface cleanup program ended in 1998. From approximately 5,000 properties and the nine uranium mill sites, 15 million cubic yards of uranium tailings were removed to controlled disposal sites. The disposal cells were constructed utilizing strict ground water, geologic, and erosion criteria. The cells are designed to last for 200–1,000 years, are erosion resistant and located primarily away from populated areas. The structures will continue to be monitored and maintained in the future by the U.S. Department of Energy (DOE).

In September 1998, the CDPHE developed and published a plan for managing uranium mill tailings encountered during construction activities in western Colorado. The Post-UMTRA Uranium Mill Tailings Management Plan provides guidance and outlines resources for building contractors, private citizens, utility companies, and local governments when faced with newly discovered uranium mill tailings material. Along with the development of responsibilities and safety procedures, the CDPHE developed a long-term disposal site in Mesa County, known as the Cheney disposal cell, which will not be totally capped and closed for several years. Recognizing the need for long-term management and storage of the remaining uncontrolled tailings, the Cheney site will remain available for UMTRA-related contaminated materials until 2023, or until the cell is filled to capacity.

For further information on the UMTRA program, visit the following CDPHE web site: http://www.cdphe.state.co.us/hm/rptailng.htm

The Uravan mill and processing site began operation in 1912 and continued operations until 1984. The site contained nearly 10 million cubic yards of radioactive tailings and processing ponds that were leaking contaminated water into the San Miguel River. In 1986, the Environmental Protection Agency added the Uravan site to its National Priorities List and cleanup remedies were implemented which include:

- Capping and revegetating 10 million cubic yards of uranium mill tailings
- Disposal of radioactive crystals from processing ponds and elimination of processing ponds
- Pumping and treating contaminated water
- Secure 12 million cubic yards of tailings along the San Miguel River
- Dismantling the two mills and most of the old buildings in the town of Uravan
- Excavation and disposal of contaminated soil

Most of the cleanup work at the Uravan site was completed in 2001 except for final remediation of the processing ponds and some long-term ground water cleanup. See Figure 10 for a photograph of Uravan in 2005.

Bulletin 40 Press Release

The Colorado Geological Survey announces the reissue of Bulletin 40, Radioactive Mineral Occurrences of Colorado. Bulletin 40 was originally published in 1978, the height of the 1970s uranium boom. It quickly sold out and, as uranium mining declined it was never reprinted. As uranium prices increased through 2003 and 2004, the Colorado Geological Survey decided to release Bulletin 40 again, this time as a CD-ROM. Bulletin 40 provides a detailed listing of all the known (1978) uranium occurrences in the state. Several plates depict the radioactive mineral occurrences on 1:250,000 scale topographic base maps. More detailed maps are included for the southwest corner of the state in the area around Naturita and Uravan. A 585-page bibliography related to uranium and thorium deposits and mining is included as Part Two of the bulletin. Bulletin 40 was written in 1978 by James L. Nelson-Moore, Donna Bishop Collins, and A.L. Hornbaker all of the Colorado Geological Survey. The Colorado Geological Survey scanned a printed copy of Bulletin 40 in an Adobe Acrobat PDF format in late 2004. The objective of this publication is to provide readily accessible information on uranium and thorium deposits in Colorado to resource developers, government planners, and interested businesses and citizens.

Copies of this publication, Bulletin 40, in CD-ROM format are available for $15 plus shipping and handling, from the Colorado Geological Survey. To order, please contact the Publications Section, 1313 Sherman Street, Room 715, Denver, CO 80203, e-mail address: pubscgs@state.co.us; Fax number: (303) 866-2461; Phone: (303) 866-2611. Visa and MasterCard are accepted. See http://geosurvey.state.co.us for a complete list of publications available through the Colorado Geological Survey.

The Future of Uranium

The use of uranium in the future will be for the production of electricity. Electrical demand is growing sharply, especially in the emerging countries of China and India. Nuclear power plants currently are and will be part of the

*See **Future** on page 12*

Future from page 11

electrical supply equation; perhaps, even more so as concerns grow about the emission of greenhouse gases from coal-fired powered plants and the price of natural gas. Nuclear power plants are expensive to build, but uranium fuel is abundant and cheap. Problems to be resolved include power plant security, eventual decommissioning, and spent fuel disposal.

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References

- Amundsen, M.A., 2002, Yellowcake towns: uranium mining communities in the American West: Boulder, Colo., University Press of Colorado, 204 p.
- Chenoweth, W.L., 1981, The uranium-vanadium deposits of the Uravan mineral belt and adjacent areas, Colorado and Utah, in Epis, R.C. and Callender, J.F. (eds.), Western Slope Colorado, New Mexico Geological Society thirty-second field Conference Guidebook, p. 165–170.
- Coffin, R.C., 1921, Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geological Survey Bulletin 16, 231 p.
- Dickinson, K.A., 1981, Geologic controls of uranium mineralization in the Tallahassee Creek uranium district, Fremont County, Colorado: The Mountain Geologist, v. 18, no. 4, p. 88–95.
- Downs, G.R. and Bird, A.G., 1965, The Schwartzwalder uranium mine, Jefferson County, Colorado: The Mountain Geologist, v. 2, no. 4, p. 183–191.
- Goodknight, C.S., Chenoweth, W.L., Dayvault, R.D., and Cotter, E.T., 2005, Geologic roadlog for Uravan mineral belt field trip, west-central Colorado: Prepared for Rocky Mountain Section Meeting of the Geological Society of America 2005 Annual Meeting.
- Nelson-Moore, J.L., Collins, D.B., and Hornbaker, A.L., 1978, Radioactive mineral occurrences of Colorado: Colorado Geological Survey Bulletin 40 (reprinted as a CD-ROM, 2005).
- Shawe, D.R., Archbold, N.L., and Simmons, G.C., 1959, Geology and uranium-vanadium deposits of the Slick Rock district, San Miguel and Dolores counties, Colorado: Economic Geology, vol. 54, pp. 395–415.
- Sheridan, D.M., Maxwell, C.H., and Albee, A.L., 1967, Geology and uranium deposits of the Ralston Buttes district, Jefferson County, Colorado: U.S. Geological Survey Professional Paper 520, 121 p.

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