EMD Uranium (Nuclear & REE) Committee

2020 EMD Uranium (Nuclear Minerals and REE) Committee Annual Report

May 27, 2020

German Nuclear Power Plant

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Michael D. Campbell, P.G., P.H., C.P.G., C.P.H., Chairman
Executive Vice President and Chief Geologist (Mining) / Chief Hydrogeologist (Environmental)
I2M Consulting, LLC, Houston, TX (Ex-Teton Exploration Div., United Nuclear Corporation, and Texas Eastern Nuclear, Inc.)
Founding Member of EMD in 1977, and Past President of EMD: 2010-2011
Fellow SEG; Fellow GSA; Fellow AIG; Fellow and Chartered Geologist GSL; EurGeol; and RM SME
Professional Licenses: TX, LA, WY, WA, and AK

May 27, 2020

A summary of this report is to be presented during the 2020 Annual EMD Zoom Conference, June 6.
Version: 1.5 (To check for updates, note Version and click (**here**)

Vice-Chairs:

- **Henry M. Wise, P.G., C.P.G., (Vice-Chair: Industry),** National Recovery Corporation, La Porte, TX (Founding Member of EMD in 1977, ex-US Steel, Uranium Div.)
- **Steven S. Sibray, P.G., C.P.G., (Vice-Chair: University),** University of Nebraska, Lincoln, NE
- **Robert W. Gregory, P.G., (Vice-Chair: Government),** Wyoming State Geological Survey, Laramie, WY

Advisory Group:

- **Kevin T. Biddle, Ph.D.,** V.P., ExxonMobil Exploration (retired), Houston, TX (Founding Member EMD in 1977)
- **James L. Conca, Ph.D., P.G.,** Senior Scientist, UFA Ventures, Inc., Richland, WA
- **Gerard Fries, Ph.D.,** Orano Mining, KATCO JV, LLP, Nur-Sultan, Kazakhstan
- **Michael A. Jacobs, P.G.,** Manager, D. B. Stevens & Assoc., Midland, TX (Founding Member of EMD in 1977, Ex-Tenneco Uranium Inc.)
- **Roger W. Lee, Ph.D., P.G.,** Consulting Geochemist, Austin, TX
- **Karl S. Osvald, P.G.,** U.S. BLM, Wyoming State Office Reservoir Management Group, Casper, WY
- **Mark S. Pelizza P.G.,** M. S. Pelizza & Associates, LLC, Plano, TX
- **Arthur R. Renfro, P.G.,** Sr. Geological Consultant, Cheyenne, WY (Founding Member of EMD in 1977, Ex-Teton Exploration Div., United Nuclear Corporation)
- **David Rowlands, Ph.D., P.G.,** Rowlands Geosciences, Houston, TX

Special Consultants to the Uranium (Nuclear and Rare Earths) Committee:

- **Ruffin I. Rackley**, Senior Geological Consultant, Seattle, WA (Founding Member of EMD in 1977, Secretary-Treasurer: 1977-1979, and President: 1982-1983, Ex-Teton Exploration Div., United Nuclear Corporation)
- **Bruce Rubin**, Senior Geological Consultant, Millers Mills, NY (Founding Member of EMD in 1977, Ex-Teton Exploration - United Nuclear Corporation, General Public Utilities, Fuel Div.)
- **M. David Campbell, P.G.**, Senior Principal and Senior Project Manager, I2M Consulting, LLC, Houston, TX. (Founder of MarineBio.org and the MarineBio Conservation Society.
- **Robert A. Arrington**, VP, Exploration, Texas Eastern Nuclear, Inc. (retired), College Station, TX (Founding Member of EMD in 1977).

UCOM COMMITTEE ACTIVITIES

The AAPG Energy Minerals Division's Uranium (Nuclear and Rare Earths) Committee (UCOM) monitors the uranium industry activities and the production of electricity within the nuclear power industry because that drives uranium exploration and development in the United States and overseas.

Input for this Annual Report has been provided by:

Henry M. Wise, P.G., C.P.G. Vice-Chair (Industry) on industry activities in uranium, thorium, and rare-earth exploration and mining;

Steven Sibray, P.G., C.P.G., Vice-Chair (University) on university activities in uranium, thorium, and rare-earth research; and

Robert Gregory, P.G., Vice-Chair (Government) on governmental (State and Federal) activities in uranium, thorium, and rare-earth research.

Special input and reviews are also provided by members of the Advisory Group.

In this report, we also provide information on current thorium and rare-earth exploration and mining, and associated geopolitical activities as part of the UCOM monitoring of "nuclear minerals," thorium and rare-earth elements (REE) activities (a function approved by the UCOM in 2011). Uranium and thorium include REE minerals in deposits in the U.S. and around the world (more).

A UCOM teleconference was held January 14, 2020 that included all three Vice-Chairs and appointed members of the UCOM Advisory Group and Special Consultants (see Agenda (here)). A follow-up meeting held later to test Zoom teleconferencing. For the purpose of reminding the members of UCOM, the Chairman reviewed the stated objectives of UCOM and received consensus. Also discussed was the renewed emphasis on the economics of mining and marketing uranium, both on Earth and off-world.

With the widespread on-set of the Coronavirus in March, 2020, the ACE 2020 to be held in early June in Houston was cancelled, Most scheduled presentations will be held on-line via Zoom, or other teleconferencing or webinar/ PPT formats. Furthermore, earlier this year, the EMD Executive Committee changed the historical format of future EMD Commodity Committee reports to one-page reports. The UCOM one-page annual report will none-the-less provide a link to this full-scale

UCOM Annual Report. In many ways, this represents the continuing degradation of many of the leading EMD commodity committee contributions, especially now that the success of gas-shales research and production by fracking has been transformed from an unconventional resource activity to conventional oil and gas activities. It should be noted that UCOM has the highest on-line visit rate of all EMD commodity webpages and associated reports.

Jay M. McMurray Memorial Grant from AAPG Foundation

UCOM is also pleased to remind the reader that the *Jay McMurray Memorial Grant* is awarded annually to a deserving student(s) whose research involves uranium or nuclear-fuel energy. This grant is made available through the AAPG Grants-In-Aid Program and is endowed by the AAPG Foundation with contributions from his wife, Katherine McMurray, and several colleagues and friends. Students having an interest in applying for the grant should contact the UCOM Chair for further information and guidance. The biography of Mr. McMurray's outstanding contributions to the uranium industry in the U.S. and overseas is available at the AAPG Foundation, 2019. We are pleased to announce that Michelle Abshire was awarded the McMurray Memorial Grant in 2020. Other recipients of the Grant since 2009 are presented in Table 1.

Table 1: Recipients of the Jay M. McMurray Memorial Grant from AAPG Foundation

2009	FORMATION OF PRECURSOR CALCIUM PHOSPHATE PHASES DURING CRYSTAL GROWTH OF APATITE AND THEIR ROLE ON THE UPTAKE OF HEAVY METALS AND RADIONUCLIDES	Olaf Borkiewicz	Miami University
2010	PRECIPITATION KINETICS OF AUTUNITE MINERALS: IMPLICATIONS FOR URANIUM IMMOBILIZATION	Denise Levitan	Virginia Tech University
2011	THE FORMATION MECHANISMS OF UNCONFORMITY- RELATED URANIUM DEPOSITS: INSIGHTS FROM NUMERICAL MODELING	Tao Cui	University of Windsor
2012	NOVEL NANOSEISMIC SURVEY TECHNIQUES IN TUNNELS AND MINES	Chiara Mazzoni	University of Strathclyde
2013	(U-TH)/HE AND U-PB DOUBLE DATING CONSTRAINTS ON THE INTERPLAY BETWEEN THRUST DEFORMATION AND BASIN DEVELOPMENT, SEVIERFORELAND BASIN, UTAH	Edgardo Pujols	University of Texas at Austin
2014	ANTHROPOGENICALLY ENHANCED MOBILIZATION OF NATURALLY OCCURRING URANIUM LEADING TO GROUNDWATER CONTAMINATION	Jason Nolan	University of Nebraska - Lincoln
2015	GEOCHEMISTRY AND DIAGENESIS OF GROUNDWATER CALCRETES: IMPLICATIONS FOR CALCRETE-HOSTED URANIUM MINERALIZATION,WESTERN AUSTRALIA	Justin Drummond	Queen's University
2016	GEOCHEMISTRY AND DIAGENESIS OF GROUNDWATER CALCRETES, WESTERN AUSTRALIA: IMPLICATIONS FOR CALCRETE-HOSTED URANIUM MINERALIZATION	Justin Drummond	Queen's University
2017	RECONSTRUCTION OF CRETACEOUS PROVENANCES OF ABEOKUTA GROUP OF THE EASTERN DAHOMEY BASIN SOUTHWESTERN NIGERIA BASED ON THE FIRST URANIUM-LEAD DETRITAL ZIRCON GEOCHRONOLOGY	Fadehan Tolulope Abosede	University of Lagos

2018	NOT AWARDED by AAPG FOUNDATION	-	-
2019	GEOCHEMICAL EVALUATION OF THE MISSISSIPPIAN LIMESTONE, ANADARKO SHELF, OKLAHOMA	Oyeleye Adeboye	Oklahoma State University
2020	TRACE METAL AND URANIUM ISOTOPE GEOCHEMISTRY OF ORGANIC-RICH SEDIMENTARY DEPOSITS	Michelle Abshire	Oklahoma State University

UCOM Publications and Nuclear Outreach

The EMD co-sponsored Journal: *Natural Resources Research* has published the bi-annual Unconventional Energy Resources: 2017 Review. Chairman Campbell, Henry M. Wise Vice-Chair (Industry), and James R. Conca (Advisory Group) of UCOM served as co-authors in the section entitled: *Uranium, Thorium, and Rare-Earth Elements: Availability and Development – Time for Recovery*. (Article, see PDF pages: 35-50). Earlier versions of the NRR articles include: the 2015 version (here); 2013 version (here); 2011 (here); 2009 (here); and 2007 (here) and all (here). The EMD contribution to the JNRR 2019 Review on The Unconventional and Alternative Energy Resources was also cancelled.

With input from older and younger members of EMD, the two-part article has been published in AAPG's *The Explorer*:

Part 1 covers EMD activities from 1968 through mid-2000, with links (here). December Issue.
Part 2 covers the years 2000 through 2018, as published (here), w/links (here). January Issue.
For the original version in manuscript form (Parts 1 and 2), with links, (here).

As a reminder, The AAPG-EMD Memoir 101: *Energy Resources for Human Settlement in the Solar System and Earth's Future in Space* was released in mid-2013 (more). The EMD's Uranium (Nuclear and REE Minerals) Committee and members of I2M Consultants, LLC, contributed the final Chapter entitled: *Nuclear Power and Associated Environmental Issues in the Transition of Exploration and Mining on Earth to the Development of Off-World Natural Resources in the 21st Century* (more). *Forbes.com* has highlighted Memoir 101 emphasizing the coverage of Chapters 8 and 9 (more).

James Conca, Ph.D., a member of the UCOM Advisory Group, continues to contribute popular articles to *Forbes.com* on many nuclear and associated energy topics. To review the chronological list of Dr. Conca's Forbes' contributions to date, see (here).

UCOM Monitoring and Coverage

UCOM management modified the format of the UCOM report a few years ago to provide greater coverage and more timely information in a more concise reporting format. To accomplish this, the UCOM members continue to examine certain topics as we have in the past, such as the issues behind the current uranium mining industry conditions and activities, and their driving forces, e.g., yellowcake prices, nuclear power plant construction, uranium reserves and world-wide exploration, especially new uranium discoveries. To support this coverage, the I2M Web Portal was upgraded and improved a few years ago, both in response speed and layout, plus it now allows multi-word searches, whereas the previous version only permitted one-word searches (more). The UCOM can now focus on particular issues covered by the I2M Web Portal by conducting and presenting search-results that are automatically updated even after we have published the UCOM reports each year so each report is in some parts at least dynamic in nature.

We draw on the I2M Web Portal database, which now contains (to May 18, 2020) almost 9,600 abstracts, some comments, with links to current technical reports and media articles from sources in the U.S. and around the world, (see the Index to all commodity and associated fields covered in the I2M Web Portal (here)). The primary emphasis of the I2M Web Portal also reflects the interests and objectives of the UCOM as a whole (2017: more) and (2019: more).

UCOM reports will be further simplified and reduced in length in the future. Beginning with this report, text reductions will be augmented by adding additional links to provide the reader with follow-on reading, should the reader wish to have additional information on the subject. It should be noted here that many links will provide direct Internet sources as well as search results from the I2M Web Portal that include summaries, some with comments on the article(s) cited in the text. This provides multiple records of historical development without selection bias.

If the search result returned a date-arranged list of summaries, the "What's New" result will continue to be updated as new entries are submitted to the database. The reader can also conduct a multi-word search of the database for related or associated topics of interest (more).

As illustrated in the summary of the 2020 UCOM Annual Report, the UCOM focus generally covers:

a) **uranium prices (**more**);**
b) **uranium geology** (more);
c) **uranium exploration** (more);
d) **uranium mining and processing** (more);

e) **uranium recovery technology** (more);

f) **nuclear-power economics** (more);

g) **reactor designs** (more); SMRs (more);

h) **operational aspects that drive uranium prices** (more);

i) **historical factors affecting plant shutdowns** (more), and

j) **related environmental and societal issues** involved in such current topics as energy resource selection and climate change (more). The latter have direct and indirect impact on the costs, mining, and utilization of uranium, thorium, and rare-earth resources.

UCOM also monitors, assesses, and reports on the status of thorium and rare-earth exploration (and development) because both are often encountered in some types of hard-rock uranium deposits, and the presence of both impact the economics of recovering uranium and rare earths, often with revenue credit for both.

UCOM coverage also includes summaries of reviews of the current developments in research on:

a) **thorium** (more),
b) **helium-3** (more), and **fusion** research (more), and
c) **nuclear used fuel (waste) storage and handling** (more).
d) **current research developments in the rare-earths** (more).

Executive Summary (Also see external submission (here).

- A significant rise in uranium prices is underway since the first of the year (2020).

- Senior U.S. uranium industry personnel indicate that recent activities concerning Section 232 requesting protection of the U.S. uranium mining industry has gained traction in the White House.

- Many uranium companies are resuming drilling properties, especially in Wyoming and Texas.

- Numerous discoveries of high-grade uranium deposits have been made in Canada and new low-grade deposits are under development in Argentina and Peru.

- The main Australian uranium mines in South Australia have resumed operations and mines in WA are preparing to resume operations.

- An undeveloped, new uranium "roll front" district has been identified in the eastern Seward Peninsula of Alaska with nearby alkaline source rocks containing high concentrations of uranium, thorium and rare-earth elements.

- Many hard-rock uranium deposits also contain associated REEs to the extent that co-production of raw REEs, thorium, and other critical metals are underway for stockpiling, awaiting shipment to processing sites around the world (more).

- Discoveries of a new uranium mineral occurring like calcrete have been made in west Texas.

- There is general agreement that substantial uranium (and thorium) will be available to fuel the U.S. as the world's largest fleet of nuclear power and producing more than 30% of worldwide nuclear generation of clean electricity.

- Some 98 nuclear power plants in the U.S. remain in operation, a few more are scheduled for retirement on the grounds of economics and low-priced natural gas, but two new reactors are being completed in Georgia.

- Following a 30-year period during which no new reactors were built in the U.S., it is expected that the two reactors will come online soon after 2021; others resulting from 16 license applications made since mid-2007 are proposing to build 24 new nuclear reactors, most of which are of the new small modular reactor (SMR) design.

- The U.S. produced about 4,015 billion (kWh) of electricity at utility-scale facilities in the U.S. in 2019. Currently, about 63% of the U.S. electricity generation is from fossil fuels (coal, natural gas, petroleum, and other gases). About 20% was from uranium providing nuclear energy, and about 17% (and rising) was from renewable energy sources of solar and wind, including hydroelectric power plants.

- Coal production and burning is falling off rapidly; but coal may be useful without burning.

- Uranium production cuts were made in 2019 in the U.S. by the world's largest uranium producers, but uncovered utility demand is expected to reach ~24% by 2021 and 62% by 2025. Hence, production should resume in the foreseeable future as the uranium price continues to rise.

- A number of mines in the U.S. (Texas, Wyoming, etc.) are either on stand-by or are available for rapid development.

- China (99 reactors by 2030), Russia (7 by 2028), Japan (now upgrading nuclear fleet), and India have aggressive nuclear power plant building programs underway.

- Saudi Arabia, South Korea, and UAE are also building nuclear power plants, some will be incorporating the new SMR designs, and "fast breeder" designs (Russia and India) that consumes most used fuel (waste), and a Russian floating nuclear power plant for use along the coast of Siberia and in the Arctic (using SMR designs).

- The U.S. Navy operates more than 40 ships and submarines with SMR nuclear power plants.

- Fusion research is progressing (more).

- ❖ Numerous sources of REE have become evident recently, e.g., in coal, fly ash, and in sea-floor deposits (more).
- ❖ Research funding by university and industry remains low, but state geological surveys (e.g., Wyoming and New Mexico) and the U.S. Geological Survey. are moving forward with robust research projects on uranium and rare earths.
- ❖ The Earth's radiation environment protected by magnetic fields continue to be monitored; and
- ❖ More medical applications in the use of radiation have emerged.

Nature and Impact of Radiation

As discussed near the end of this report, as in past reports, we have updated the information on radiation, whether it relates to that arriving from deep space, mitigated by the strength of our Sun's radiation, or whether it relates to the changing characteristics of the Earth's magnetic fields, which serve to form barriers against solar and deep-space radiations coming into the Earth's atmosphere.

The nature and impact of radiation, perceived and real, have been emphasized over the years by a variety of anti-mining and nuclear-power adversaries. In an attempt to educate AAPG members and the general public, UCOM has been addressing these important issues since the beginning in 2004, reporting within the UCOM on the fear of radiation (e.g., 2005), while continuing to address the issues surrounding human-health issues in greater detail over the past few years (more) and (more).

Because the effects of radiation are difficult to put into perspective by many, and even misinterpreted or exaggerated by agenda-driven adversaries, UCOM portrays radiation in context with our environment on Earth, in the atmosphere, in the orbital reaches, and in deep space (more). And, like coal, there are beneficial uses of radiation in more than one medical field, even quite possibly against the coronavirus.

With respect to other environmental issues involved in uranium exploration and mining, UCOM also monitors, assesses, and reports on matters related to radiation in the environment on Earth. This is based on the fact that one of the principal environmental issues surrounding the expansion of nuclear power as an energy source is fear of radiation, the actual impact of which has been exaggerated in the past in the media, and especially in movies and news reports of the 1970s and 1980s (more).

Also, of specific interest to geoscientists working in field conditions, UCOM reports include the Alerts Program, from the I2M Web Portal. The editors monitor and select articles for review on potentially hazardous field conditions. This illustrates that there are real hazards ranging from earthquakes, tsunami, meteorological, natural and human-induced hazards (such as the coronavirus) other than radiation that surrounds us all (Field Alerts: more).

There are other on-going monitoring programs underway at via the I2M Web Portal. These include Security Alerts: (more), which covers computer-hacking warning events and cyber-security issues, and media bias monitoring relating to uranium mining and nuclear power in general (more).

Historical Perspective

Now that we can look back and separate: a) the clear damage done by our use of atomic weapons to end World War II in Japan from b) the use of nuclear energy for peaceful purposes in harnessing this energy for generating electricity, we also have learned that the actual impact of a nuclear-core meltdown can be managed. For example, no one died or was irradiated as a result of the Three Mile Island incident (more), nor as a result of the damage by the tsunami on the nuclear plants in Japan (more).

The Chernobyl disaster is in a different class. Because of the Soviet Union's expediency used in designing reactors (as a result of "Cold War" competition with the rest of the world), safety issues were largely ignored (more). This resulted in an over-reaction to contain the highly radioactive fires of the cores after the explosions. Emergency personnel were rushed into service, which irradiated and killed more than 30 brave emergency responders, such as fire-fighters, paramedics security workers, and no doubt senior party members in charge of local politics, and inflicted thyroid cancer on thousands of children. However, almost 99% of the children were quickly treated and recovered (more).

The nuclear industry also now knows how to handle such core breaches, learned by the Japanese and the rest of the on-looking world in 2011. Evacuations were largely safety measures; fear was the main outcome, but no one was irradiated or died managing the core breach caused by the loss of standby power. The other undamaged reactors at the plant site continued in operation (more). The aerial extent of dangerous radiation turned out to be minimal, although the residual fear prevented many nearby residents from returning to their homes. Counseling and education have helped many to understand radiation and to gain a new perspective of radiation that surrounds us all (more). As a result, new safety measures in plant design and in emergency response are being implemented and many of the nuclear power plants in Japan are coming back on-line, driven by the "all-clear" of minimal residual radiation and the high prices of imported natural gas, and by the slow build-up and cost of renewable energy (more). The wastes from the incident are being managed (more).

Germany and Austria remain anti-nuclear, but that resolve is weakening based on the growing perception of nuclear power's actual safety record, having new information on emissions, and being made aware of the new, innovative ways of managing radioactive waste. As will be discussed later in this report, the small, modular reactors (SMRs) will soon be available, which will cut the construction costs considerably from that of previous large-scale nuclear reactors, while maintaining safety, reliability and support of the power grid with minimal interruptions.

Nuclear Power Plants Demand Fuel

Uranium prices and exploration and mining are driven by nuclear-plant demand for fuel for the 96 reactors currently in operation in the U.S. and the 440 reactors worldwide (and for those under construction/planned in the future). Plants also must plan for the storage of their own "used" fuel in the U.S., (which is not all "waste" because some will likely be useful in the future). This is because the U.S. federal government failed to provide the national storage facility mandated by law decades ago while still charging nuclear plants billions of dollars to build Yucca Mountain Facility (without success to date), and which also failed to manage the plants' radioactive used fuel, when alternative storage locations were available, e.g., the WIPP project in New Mexico (more). Plants are currently storing their used fuel on site in dry casks approved by EPA (more), which if they were collected and stored on one site would only require an area the size of an American football field stacking the casks 10-feet high (more).

With 440 nuclear power plants in current operation worldwide, they require some 23 million pounds of yellowcake to be available for processing to fuel pellets to meet the various 3-5 year cycles of the plants. As each new plant construction is announced, an additional 50,000 pounds will be needed 5-10 years in the future to fuel the new plant and then the same every 3 to 5 years hence. This would stimulate new mine production or an expansion of existing mines, should the mines have such capabilities. The world's yearly uranium production (through 2018) has been no more than 120 million pounds (U_3O_8) over the past 10 years (more).

Some mines in Canada, Australia, and perhaps Kazakhstan and others have significant expansion capabilities, e.g., Cigar Lake, McArthur River in Canada, and Inkai in Kazakhstan. But new, large deposits (some very high grade) have been discovered around the rim of the Athabasca Basin of Saskatchewan and Manitoba, Canada, and in breccia pipe deposits in Arizona (more), and as roll-front deposits in basins elsewhere in the world (i.e., Peru, Uruguay and Paraguay, India, Iran, and Tanzania.

World nuclear power plant requirements for 2020 was indicated at 68,240 tonnes (or 80,472 tonnes of U_3O_8 or 177 million pounds of U_3O_8) (more); any shortfalls were made up from the U_3O_8 held by utilities, dealers, and governments. The White House has recently recognized the value of the U.S. uranium mining industry (more).

The recent move by the WH to provide some protection to the U.S. uranium mining industry is based on the fact that uranium has been purchased by U.S. utilities from potentially unstable sources now that Russia no longer sends the U.S. its outdated nuclear war heads for down-grading and fabrication into nuclear fuel for power plants (see Figure below). The program ended in 2013, about the time Russia began showing signs of instability. Russia has ownership of some uranium production in the U.S. and elsewhere, but it represents a small percentage of the whole in the U.S.

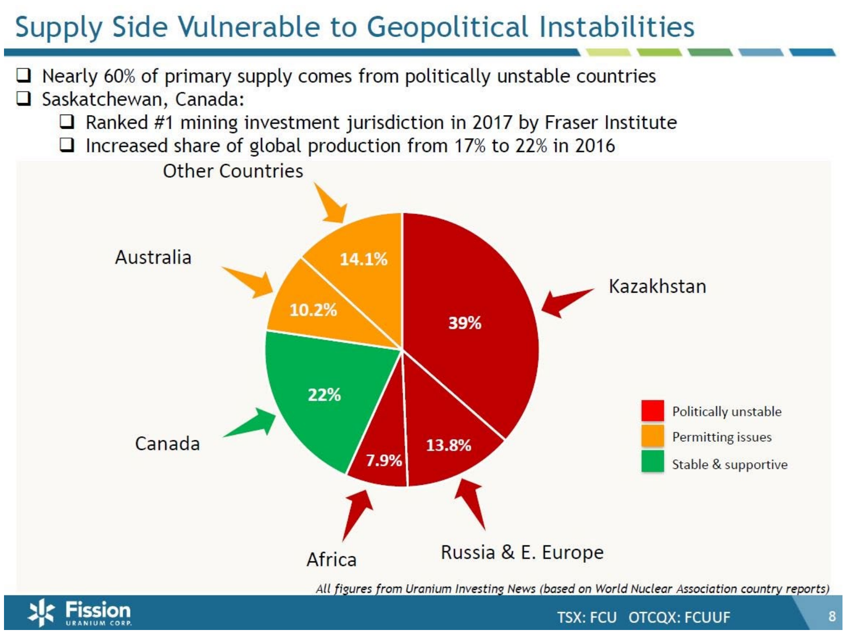

Figure 1 (Fission Uranium)

If the new WH program replaces the 13.8% of the uranium previously sold by Russia to the U.S. with American-produced uranium, the remaining countries in the figure above can be considered stable sources for now.

U. S. Uranium Production

U.S. production of uranium concentrate (U_3O_8) in the first quarter of 2020 was 8,098 pounds, down 79% from the fourth quarter of 2019 and down 86% from the first quarter of 2019. During the first quarter of 2020, four U.S. uranium facilities produced uranium, one less than in the fourth quarter of 2019. Total production of U.S. uranium concentrate from all domestic sources in 2019 was 0.17

million pounds of U_3O_8, 89% less than in 2018, from six facilities: five in-situ leaching and one underground mine.

U.S. uranium in-situ leach plants in production (state):

- Lost Creek Project (Wyoming)
- Nichols Ranch In-Situ Recovery (ISR) Project (Wyoming)
- Ross Central Processing Plant (CPP) (Wyoming)
- Smith Ranch-Highland Operation (Wyoming)
- North Butte In-Situ Recovery (ISR) Project

Total 2019 U.S. Production

U.S. uranium mines produced 0.17 million pounds of uranium (aka triuranium octoxide) (U_3O_8), or uranium concentrate in 2019, 76% less than in 2018. The production of uranium concentrate is the first step in the nuclear fuel production process. The U_3O_8 is then converted into UF_6 to first enable uranium enrichment, then fuel pellet fabrication, and finally fuel assembly fabrication.

Total shipments of uranium concentrate from domestic producers were 0.19 million pounds U_3O_8 in 2019, 87% less than in 2018.

By the end of 2019, Shootaring Canyon Uranium Mill in Utah and Sweetwater Uranium Project in Wyoming were on standby with a total capacity of 3,750 short tons of material per day. The White Mesa Mill in Utah, which had a capacity of 2,000 short tons of material per day, was not producing uranium. In Wyoming, one heap leach plant was in the planning stages (Sheep Mountain).

EIA personnel (2020) estimated the U.S. uranium reserves were 31 million pounds U_3O_8 at a maximum forward cost of up to $30 per pound. At up to $50 per pound, reported estimated reserves were 206 million pounds U_3O_8. At up to $100 per pound, reported estimated reserves were 389 million pounds U_3O_8. These reserves are a fraction of likely total domestic uranium reserves because EIA personnel did not include inferred resources that were not reported because of a lack of cost estimates or because the reserves were not located on actively managed properties.

The uranium reserve estimates presented here cannot be compared with the much larger historical data set of uranium reserves published in the July 2010 report *U.S. Uranium Reserves Estimates*.

EIA estimated those reserves based on data they collected and data the National Uranium Resource Evaluation (NURE) program developed, which is based on speculation. The EIA data include about 200 uranium properties that have reserves, collected from 1984 through 2002. The NURE data include about 800 uranium properties with reserves, developed from 1974 through 1983.

Although the data collected on the Form EIA-851A survey covers a much smaller set of properties than the earlier EIA data and NURE data, EIA personnel now conclude (2020) that within its scope the Form EIA-851A data provide more reliable estimates of the uranium recoverable at each forward cost than the estimates derived from 1974 through 2002. In particular, the Form EIA-851A data are more reliable because the NURE data have not been comprehensively updated in many years and are no longer considered a current data source for such purposes, although very useful in frontier and trend exploration projects by the uranium industry in the past and future.

Value of World-Wide Uranium Supplies

Uranium occurrences are common in a number of areas in the U.S. Some are located in remote areas and some occur within known aquifers below populated areas (see pages 14-19). Aside from the very large, undeveloped uranium deposit in Virginia, the top uranium mines and new discoveries are in Canada, Australia, Kazakhstan, South America and others, there will be no shortage of fuel supplies from producing mines for many decades at least and from the new anticipated production to come (more).

With a plethora of sources available, uranium production may be controlled for the purpose of supporting production costs in the U.S. and elsewhere. As indicated to date, 35 countries account for U_3O_8 resources in the ground (equivalent to about 10 billion pounds U_3O_8), which would provide utilities with fuel for some 100 years based on a worldwide consumption rate of 50 million pounds U_3O_8/year over a 3-year fuel cycle for 450 reactors (more).

Nuclear power is now expected to expand in the coming years (as the large-scale solar and wind projects' operation and maintenance costs drive up electricity costs), the number of reactors are expected by some experts to rise from the current 450 to 1,400 operational reactors by 2050. By 2075, large fusion power plants will likely be on the rise to supply the all-electric power grid worldwide. Both fission and fusion plants will likely co-exist over the next 100 years as fusion is perfected as the principal power source on Earth but also for use off-world as new fusion-powered ships begin to approach light speed.

Based on recent discoveries in Canada alone, its percent of acknowledged world reserves will increase considerably. One condition that could develop is a long-term over supply of uranium to be produced from a plethora of high- and low-grade deposits that would keep prices even below

$50.00/ pound, below that required for some of the in-situ mines in the U.S. to operate economically. Some grades reported in Canadian deposits are so high that the beginning of robotic mining could well be in the offing. This could raise the cost to mine and transport such high-grade ore in the beginning, but costs would decrease as the technology settles in (more).

Substantial investment money is coming into the new Canadian uranium discoveries to support the development of these high-grade deposits (more), including the Chinese who are buying into mines in Canada (more) and in Namibia (more); mine development is also available with Russian funding (more). But what will the demand be in the foreseeable future to fuel the expanding fleet of nuclear power plants in the U.S. and worldwide? If Chinese and Indian projection come to pass, fuel needs will rise significantly over the next 10 years and beyond as will the uranium price.

Drilling within uranium prospects is very active in Africa, and South America, in China, and in Australia and Asia; although the latter has substantial uranium potential, it is still suffering from political fatigue in all uranium states, although discussions are currently under way about encouraging nuclear power to replace coal and some new renewables with increasingly expensive electricity costs (Western Australia, Northern Territory, Queensland, and even South Australia) (more). The emphasis on nuclear power by China is reflected by numerous frontier uranium exploration projects being conducted by Chinese geologists, as reported by Steven Sibray, Vice-Chair, UCOM (University) later in this report.

FUEL COMPETITION

Updated citations on topical issues:

1. Coal vs. Nuclear Power and Natural Gas (here)

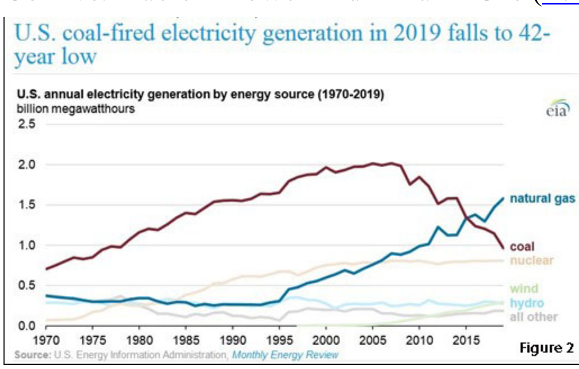

Figure 2

2. Renewable Energy vs. Nuclear Power (here)
3. Industry Bias: Google Search Results: (here)
4. Academic Bias: Google Search Results: (here)

Thorium Activities Summary

Thorium-Based Reactors continue development in the U.S., but especially in China and India (more). The WNA presented a 2017 status review of thorium resources and engineering experts opine on reactor development to date.

Updated citations topical issues related to thorium research:

1. I2M Web Portal: Search Results: Thorium (more)
2. University Research: Google Search: Thorium (more)
3. Industry Research: Google Search: Thorium (more)

Rare Earth Activities Summary

1. I2M Web Portal: Search Results "Rare Earth" REE (more)
2. University Research: Google Search Results (more)
3. Industry Research: Google Search Results (more)

ADVERSARIES of URANIUM MINING and NUCLEAR POWER DEVELOPMENT

1. Industry Media Bias (more)
2. Academic Bias (more)

URANIUM and RARE EARTH UNIVERSITY RESEARCH

By Steven S. Sibray, P.G., C.P.G., (Vice-Chair: University), University of Nebraska, Lincoln, NE

Interest in uranium and thorium research has decreased since the Fukushima Daiichi nuclear accident in 2011 with very few grants and new sources for funding. Interest in Rare Earth Elements [REE] research has also decreased somewhat due weak market conditions. Lack of career opportunities in the uranium mining might also be a factor in the apparent absence of student interest in pursuing research related to uranium exploration. News on the recent increases in the spot price of uranium is probably not enough to offset the extreme pessimism concerning the future of the uranium mining industry among geology students looking at future employment in mineral exploration.

The Society of Economic Geologists Foundation (SEGF) and the SEG Canada Foundation (SEGCF) recently announced the Student Research Grant awards for 2019. These grants assist students with field and laboratory expenses for thesis research on mineral deposits as required for graduate degrees at accredited universities. Grants are awarded on a competitive basis and are available to students worldwide. Of the 51 grants awarded, only one was granted for the study of Rare Metals [RM] which includes uranium and thorium as well as Li, Be, Ti, Zr, Nb, Ta. None of the grants were awarded for the study of REE deposits. The one grant was from the Timothy Nutt Fund which was established as a memorial to Timothy Nutt. Mr. Nutt was a world-renowned economic geologist who specialized in the study of ore deposits of Africa.

Timothy Nutt Grant

Godfrey Chagondah	US$4,600	University of Johannesburg (South Africa)	Ph.D.	Petrogenesis and Metallogenesis of Rare-Metal Granitic Pegmatites Along the Southern Margin of the Zimbabwe Craton

Colorado School of Mines

John DeDecker completed his doctoral thesis on the fluid-rock interactions responsible for forming the unconformity-related uranium deposits in the Athabasca Basin. The tile of his thesis is "Alteration and mineral paragenesis of the McArthur River and Fox Lake uranium deposits, Athabasca Basin: a new model for the formation of unconformity-related uranium deposits."

Dr. DeDecker is now working on a post-doctoral fellowship on a gold-rich volcanogenic massive sulfide deposit. At the present time, there are no graduate students at the Colorado School of Mines conducting research on either uranium or REE deposits.

New Mexico Institute of Mining and Technology

Dr. Virginia McLemore at New Mexico Institute of Mining and Technology has been active in uranium and REE research and has provided a list of publications and abstracts published in 2019.

McLemore, V.T., 2019, Critical minerals in New Mexico: SME Annual Meeting, Preprint 19-132, 6 p., https://geoinfo.nmt.edu/staff/mclemore/projects/documents/19_132.pdf

McLemore, V.T., 2019, Preface to the MME Special Issue on Critical Minerals Part I: Mining, Metallurgy & Exploration, p. 1-3, DOI 10.1007/s42461-019-00128-1 URL: https://link.springer.com/content/pdf/10.1007/s42461-019-00128-1.pdf

University of Regina [Canada]

Morteza Rabiei, graduate student in geology, won the 2019 "Saskatchewan Innovation and Excellence Graduate Scholarship". The scholarship was awarded to him for his effort in understanding the origin of the recently discovered deep-seated uranium deposits in the Patterson Lake corridor in the western Athabasca Basin, northern Saskatchewan.

Supported by the Geological Survey of Canada Targeted Geoscience Initiative (TGI) program and an NSERC-Discovery Grant (to his supervisor Dr. Guoxiang Chi), Morteza's research focuses on characterization of the ore-forming fluids and comparison with those from the eastern part of the basin. Morteza also won this scholarship in 2018 for his innovative research on the hydrothermal rare earth element (REE) mineralization of the Maw Zone deposit in the Athabasca Basin. This research was published in 2017:

> Rabiei M., G. Chi, C. Normand, W. J. Davis, M. Fayek, and N. J. F. Blamey, 2017, "Hydrothermal Rare Earth Element (Xenotime) Mineralization at Maw Zone, Athabasca Basin, Canada, and Its Relationship to Unconformity-Related Uranium Deposits," *Economic Geology,* 112 (6): pp. 1483–1507.URL: http://www.i2massociates.com/downloads/Rabiei2017AthabascaU.pdf
> Reply: http://www.i2massociates.com/downloads/ChiReply.pdf

Dr. Guoxiang Chi was the lead author of an interesting paper in Ore Geology Reviews comparing the hydrothermal uranium deposits at the Beaverlodge district in Canada with hydrothermal uranium deposits in South China. The authors of this paper proposed a genetic model that explains the origin of these granite related hydrothermal vein uranium deposits. The model emphasizes the coupling of shallow (extensional red bed basin) and deep-seated (asthenosphere upwelling and related extensional faulting and magmatism) as the primary controls of the uranium mineralization. The source of oxidizing fluids is related to red bed deposition. A diagram of this model is shown in Figure 3:

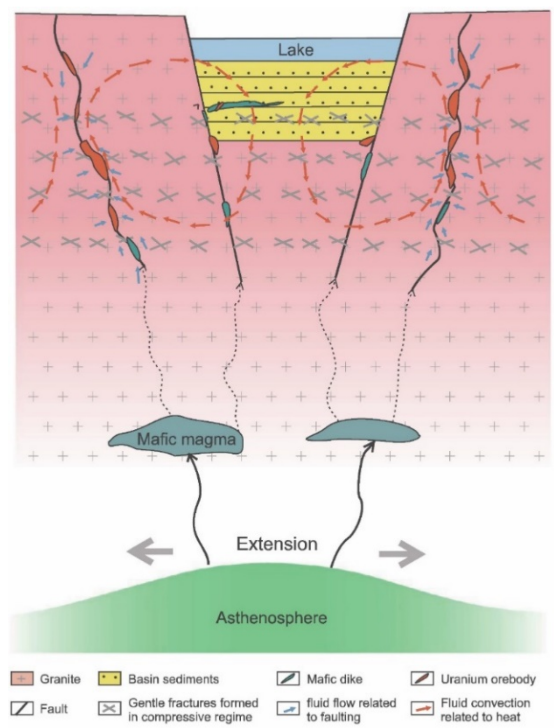

Figure 3 (Chi, et al., 2020)

> Chi, G., K. Ashton, T. Deng, D. Xu, Z. Li, H. Song, R. Liang, and J. Kennicott, 2020, "Comparison of granite-related uranium deposits in the Beaver Lodge district (Canada) and South China – A common control of mineralization by coupled shallow and deep-seated geologic processes in an extensional setting," *Ore Geology Reviews*, Volume 117, article 103319, ISSN 0169-1368. URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136819308042-main.pdf

Research by Dr. Guoxiang Chi and former Ph.D. student Haxia Chu (now with China University of Geosciences, Beijing), based on LA-ICP-MS analysis of fluid inclusions entrapped in quartz overgrowths in sandstones, revealed that the diagenetic fluids within the Athabasca basin contained up to 27 ppm U. This is two orders of magnitude higher than most naturally occurring geologic fluids. The research results, published by *Scientific Reports*, provide the key to understand why the Athabasca Basin is so rich in uranium deposits. This suggests there is potential of finding more world-class uranium deposits underneath the basin. The paper is open access and can be downloaded here: https://rdcu.be/bulW0

University of Wyoming

An important paper on the results of a sulfur isotope study of pyrite from the Lost Creek and the Willow Creek Mine roll-front deposits was published in *Economic Geology* in 2019 by researchers at the University of Wyoming. This study revealed that both deposits had both abiogenic and biogenic redox mechanisms as active contributors to ore formation. However, the Lost Creek deposit was reportedly propagated largely through abiogenic pyrite recycling in a buffered solution at near-neutral pH. Sulfur isotope trends from abiogenically derived pyrite indicated that ore precipitation was predominantly driven by an Eh drop across the roll under conditions of buffered, near-neutral pH.

In contrast, the Willow Creek Mine [Unit #10] mineralization was controlled by biogenic redox where the sulfur isotopes of framboidal pyrite indicated rapid bacterial sulfate reduction and prolific bacterial activity. Strong Eh/pH gradients in the Willow Creek Mine Unit 10 were confirmed by the presence of marcasite and other minerals indicative of low pH. The chemical conditions of these deposits strongly influenced the resultant ore assemblages. Willow Creek Mine Unit 10 is dominated by tyuyamunite mineralization and is the consequence of biogenic redox. Lost Creek, which formed through abiogenic redox, contains primarily coffinite, uraninite, and brannerite. The roll-front deposits where hexavalent uranium minerals such as carnotite and tyuyamunite are dominant are obviously less soluble and are less desirable for in situ recovery mining. The citation for this paper is as follows:

> Hough, G., Swapp, S., Frost, C., Fayek, M. (2019) *Sulfur isotopes in bacterially and chemically controlled roll-front deposits*. *Econ. Geol*., 114: pp. 353-373.URL: http://www.i2massociates.com/downloads/Hough2019RollU.pdf

Ore Geology Reviews

A few noteworthy research papers on the geology and mineralogy of the Bayan Obo Fe-REE-Nb deposit which is the world's largest resource of REE. To understand the genesis of this unique deposit, the authors conducted detailed mineralogical observations using scanning electron microscope (SEM), cathodoluminescence (CL) and in-situ micro-analyses on chemical compositions of the dolomite and apatite by EPMA and LA-ICPMS techniques. The primary source of REE was a carbonatite intrusive which has undergone multistage hydrothermal metasomatism when Sr-rich, Na-depleted and REE-poor metamorphic fluid flowed into the deposit and resulted in REE remobilization. The reference is found here:

Yisu Ren, Xiaoyong Yang, Shuangshuang Wang, Hüseyin Öztürk, 2019, *Mineralogical and geochemical study of apatite and dolomite from the Bayan Obo giant Fe-REE-Nb deposit in Inner Mongolia: New evidence for genesis, Ore Geology Reviews*, Volume 109, pp. 381-406, ISSN 0169-1368. URL: https://www.i2massociates.com/downloads/Mineralogicalandgeochemicalstudyofapatiteanddolomitefromthe.pdf

Articles on the uranium deposits of China were prominent in the 2019 issues of *Ore Geology Reviews*. Below are the references for these studies:

Qiang Zhu, Reng'an Yu, Xiaoxi Feng, Jianguo Li, Xianzhang Sima, Chao Tang, Zenglian Xu, Xiaoxue Liu, Qinghong Si, Guangyao Li, Sibo Wen, 2019, *Mineralogy, geochemistry, and fluid action process of uranium deposits in the Zhiluo Formation, Ordos Basin, China*, *Ore Geology Reviews*, Volume 111, article 102984, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818303846-main.pdf

Zenglian Xu, Jianguo Li, Qiang Zhu, Jialin Wei, Hongliang Li, Bo Zhang, 2019, *Late Cretaceous paleoclimate change and its impact on uranium mineralization in the Kailu Depression, southwest Songliao Basin*, *Ore Geology Reviews*, Volume 104, pp. 403-421, ISSN 0169-1368 URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818303214-main.pdf

Yanyan Li, Chengjiang Zhang, Guoxiang Chi, Ji Duo, Zenghua Li, Hao Song, 2019, Black and red alterations associated with the Baimadong uranium deposit (Guizhou, China): *Geological and geochemical characteristics and genetic relationship with uranium mineralization*, *Ore Geology Reviews*, Volume 111, article 102981, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818310692-main.pdf

Long Zhang, Chiyang Liu, Kaiyu Lei, 2019, *Green altered sandstone related to hydrocarbon migration from the uranium deposits in the northern Ordos Basin*, China, *Ore Geology Reviews*, Volume 109, pp. 482-493, ISSN 0169-1368

Chengyong Zhang, Fengjun Nie, Yangquan Jiao, Wei Deng, Yunbiao Peng, Shuren Hou, Mingjian Dai, Tengfei Ye, 2019, *Characterization of ore-forming fluids in the Tamusu sandstone-type uranium deposit, Bayingobi Basin, China: Constraints from trace elements, fluid inclusions and C–O–S isotopes*, *Ore Geology Reviews*, Volume 111, article 102999, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818303664-main.pdf

Liang Yue, Yangquan Jiao, Liqun Wu, Hui Rong, Huili Xie, Qianyou Wang, Qianqian Yan, 2019, *Selective crystallization and precipitation of authigenic pyrite during diagenesis in uranium reservoir sand bodies in Ordos Basin*, *Ore Geology Reviews*, Volume 107, pp. 532-545, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818303597-main.pdf

Jiangnan Zhao, Shouyu Chen, Renguang Zuo, Mi Zhou, 2019, *Controls on and prospectivity mapping of volcanic-type uranium mineralization in the Pucheng district, NW Fujian, China*, *Ore Geology Reviews*, Volume 112, article103028, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818307431-main.pdf

Fei Hu, Jianguo Li, Zhaojun Liu, Dingming Zhao, Tao Wan, Chuan Xu, 2019, *Sequence and sedimentary characteristics of upper Cretaceous Sifangtai Formation in northern Songliao Basin, northeast China: Implications for sandstone-type uranium mineralization*, *Ore Geology Reviews*, Volume 111, article 102927, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818304669-main.pdf

Lulu Chen, Yin Chen, Xiaoxi Feng, Jian-guo Li, Hu Guo, Peisen Miao, Ruoshi Jin, Chao Tang, Hualei Zhao, Gui Wang, Shuguang Li, 2019, *Uranium occurrence state in the Tarangaole area of the Ordos Basin, China: Implications for enrichment and mineralization*, *Ore Geology Reviews*, Volume 115, article103034, ISSN 0169-1368.URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818303676-main.pdf

Zhi-Qiang Yu, Hong-Fei Ling, John Mavrogenes, Pei-Rong Chen, Wei-Feng Chen, Qi-Chun Fang, 2019, *Metallogeny of the Zoujiashan uranium deposit in the Mesozoic Xiangshan volcanic-intrusive complex, southeast China: Insights from chemical compositions of hydrothermal apatite and metal elements of individual fluid inclusions*, *Ore Geology Reviews*, Volume 113, article 103085, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136819303592-main.pdf

Yin Chen, Ruoshi Jin, Peisen Miao, Jianguo Li, Hu Guo, Lulu Chen, 2019, *Occurrence of pyrites in sandstone-type uranium deposits: Relationships with uranium mineralization in the North Ordos Basin, China, Ore Geology Reviews*, Volume 109, pp. 426-447, ISSN 0169-1368, URL: http://www.i2massociates.com/downloads/1-s2.0-S0169136818305651-main.pdf

URANIUM & RARE EARTH GOVERNMENT RESEARCH

By Robert W. Gregory, P.G., (Vice-Chair: Government), Wyoming State Geological Survey, Laramie, WY

The WSGS continues to focus much of its field mapping efforts on REE and other critical minerals as outlined by the USGS (Fortier and others, 2018).

Fortier, S.M., Nassar, N.T., Lederer, G.W., Brainard, Jamie, Gambogi, Joseph, and McCullough, E.A., 2018, Draft critical mineral list—Summary of methodology and background information—U.S. Geological Survey technical input document in response to Secretarial Order No. 3359: U.S. Geological Survey Open-File Report 2018–1021, 15 p., URL: https://pubs.usgs.gov/of/2018/1021/ofr20181021.pdf

Current mapping and sampling projects are in the planning stages for both igneous and sedimentary deposits of critical minerals. The USGS's Earth MRI (Mapping Resources Initiative) seeks to enhance our knowledge of potential of certain focus areas throughout the United States in an effort to decrease our dependence on foreign suppliers of REE and other critical minerals. For more information on the Earth MRI program visit their website (https://www.usgs.gov/science-explorer-results?es=earth+mri).

The WSGS is also using handheld x-ray fluorescence (HXRF) to survey cores from ISR uranium operations to gain a better understanding of subtleties in the occurrences of uranium and vanadium (as well as REE and other critical minerals).

The U.S. Geological Survey (USGS) has published several uranium-related articles recently. Their efforts to assess critical minerals has pulled much of their personnel away from uranium resource projects. In June, the USGS uranium resource project (Susan Hall) will publish a paper describing the genetic deposit model for calcrete uranium in the Southern High Plains. The Southern High Plains uranium province is the first new type of uranium occurrence identified in the U.S. in at least 30 years. This area was first explored for its uranium potential by Kerr McKee in the late 1970s and early 1980s, but the yellow mineralization that was observed in outcrop was presumed to be superficial. Carnotite and finchite [a new yellow mineral composed of strontium, hexavalent uranium, and vanadium] was likely precipitated by the evaporation of uranium- and vanadium-rich groundwater in discharge areas in the eastern portion of the southern High Plains. The source of the uranium may have been from the underlying Triassic Dockum Formation sediments.

Historic resources of known calcrete-uranium deposits in the Southern High Plains were estimated at 1.4 to 2.7 million pounds U_3O_8 using a cutoff grade of 250 ppm U_3O_8. The USGS has completed an assessment of the region, a compilation of known grade and tonnages of other world calcrete deposits, and description of the geology of known deposits in the Southern High Plains and work in this area is now complete:

Hall, S.M., Van Gosen, B.S., Paces, J.B., Zielinksi, R.A., Breit, G.N., 2019, Calcrete uranium deposits in the Southern High Plains, USA, Ore Geology Reviews, v. 109, June 2019, p. 50-78https://doi.org/10.1016/j.oregeorev.2019.03.036

Hall, S.M., Mihalasky, M.J., and Van Gosen, B.S., 2017, Assessment of undiscovered resources in calcrete uranium deposits, Southern High Plains region of Texas, New Mexico, and Oklahoma, 2017: U.S. Geological Survey Fact Sheet 2017–3078, 2 p., https://doi.org/10.3133/fs20173078

Van Gosen, B.S., and Hall, S.M., 2017, The discovery and character of Pleistocene calcrete uranium deposits in the Southern High Plains of west Texas, United States: U.S. Geological Survey Scientific Investigations Report 2017–5134, 27 p., https://doi.org/10.3133/sir20175134.

Hall, S.M. and Mihalasky M.J., 2017, Grade, tonnage, and location data for world calcrete-type surficial uranium deposits: U.S. Geological Survey Data Release. https://doi.org/10.5066/F7MS3RQS

The USGS uranium resources project is now focused on developing a genetic model for the giant Coles Hill uranium deposit in Virginia, first discovered by the Duke Energy's uranium exploration team in the early 1970s (more). For the current work, the USGS has partnered with the VA Museum of Natural History, who own and curate historic cores recovered at Coles Hill, and are working with geoscientists with VA Tech, and Virginia Uranium. Through some micro-structural work, mineral microscopy and geochronology, the USGS has just published dates of minerals associated with mineralization at the Southeast section of the GSA meeting in March 2019. The following abstracts address the Coles Hill deposit:

Aylor, J., Beard, J.S., Bodnar, R.J., Potter, C.J., Hall, S.M., 2018, Veins, fractures and paragenesis, Coles Hill uranium deposit, Pittsylvania County, Virginia, (abs.), SE Section GSA Abstracts with Programs, Vol. 50, No. 3. https://doi.org/10.1130/abs/2018SE-311784

Hall, S.M., Breit, G.N., Zielinski, R.A., 2018, Mineral paragenesis of the Coles Hill uranium deposit, Pittsylvania County, VA, (abs.), SE Section GSA Abstracts with Programs, Vol. 50, No. 3. https://doi.org/10.1130/abs/2018SE-311606.

The USGS uranium resources project is also hoping to examine in some detail the development of a uranium deposit and mineralogy database with Simone Runyon and following up on an abstract published in 2018:

Runyon, S.E., Hall, S.M., Perry, S.N., Eleish, A., Prabhu, A., Morrison, S.M., Liu, C., Golden, J., Pires, A., Smith, M.L., Wendlandt, R.F., Zhong, H., Fang, H., Burns, P.C., Hazen, R.M., 2018, U-bearing mineral chemistry and its relation to uranium ore deposit types, (extended abs.) Deep Time Data-driven Discovery Workshop, Washington DC, 4-6 June, 2018, https://www.4d-workshop.net/

Also in 2017, Hall, Mihalasky, Tureck, and Hannon released a study entitled: *Genetic and grade and tonnage models for sandstone-hosted roll-type uranium deposits, Texas Coastal Plain, USA*. The paper examines geologic and climatic factors which led to the development of about 160 million pounds of eU_3O_8, about 60 million pounds of which remains in mineable deposits. Also with the USGS, Tanya Gallegos and her colleagues examined drill-core samples from an ISR mining operation in the Powder River Basin, Wyoming to determine the nature of uranium occurrences following mining and restoration. The paper is entitled: *Persistent U(IV) and U(VI) following in-situ recovery (ISR) mining of a sandstone uranium deposit, Wyoming, USA* (https://pubs.er.usgs.gov/publication/70159787).

The study examined tetravalent (IV) and hexavalent (VI) uranium occurrences and their relationships to the type of host strata and found that both forms remain after mining and restoration, and they are not homogenously distributed. The team is hoping to gain insight into the mobility of uranium after establishing reducing conditions.

The Wyoming State Geological Survey (WSGS) has recently published a summary of the geology, mining/production history, and remaining minable uranium resources of the Gas Hills district in central Wyoming in open file or information circular format (Gregory, R.W., (2019), *Uranium Geology and Resources of the Gas Hills District, Central Wyoming*.

The WSGS is also in the early stages of collaboration with the University of Wyoming, Department of Geology and Geophysics (UWGG) and the UW School of Energy Resources (SER) to examine the nature of REE occurrences in the roll-front environment. Dr. Simone Runyon of UWGG will head that project. Along with those efforts, the WSGS also plans to examine the occurrence and potential of critical minerals/elements in association with roll-front uranium deposits, in support of the REE work.

In April 2019, the WSGS published an open file report detailing the work of Jesse R. Pisel and Charles P. Samra which presents a model from over 40,000 samples analyses. The goal is to identify areas of interest for future mineral and elemental investigations, both with higher potential for mineralization, and by surveying areas where analytical data are lacking.

The study uses geochemical analyses of sediment samples from the National Uranium Resource Evaluation (NURE) and uses geostatistical to filter data. See more at the WSGS website:

> Pisel, J.R., and Samra, C.P., 2019, Regional-scale geochemical investigations from legacy rock and sediment datasets: Wyoming State Geological Survey Open File Report 2019-2, 20 p. URL: https://www.wsgs.wyo.gov/

For information on current and older research projects at the USGS, visit their comprehensive website (more). Additional uranium research subjects investigated by the U. S. Geological Survey and other state and overseas geological surveys are available for review via the I2M Web Portal and its multi-word search facility (more) Additional rare-earth research subjects investigated by the U. S. Geological Survey and other State and National Surveys are also available for review (more).

Ambient Radiation and Other Potential Hazards from Space

UCOM reports include discussions of the radiation occurring offworld in space and of that coming into our atmosphere, some of which making it to the Earth, for the purpose of informing AAPG members and the general public that radiation is not only emitted by naturally occurring radioactive minerals containing uranium, radium, and thorium (that emit alpha, beta, and gamma radiation), but also by energy sources in our Sun (emerging as sunlight but also as coronal mass ejections (CMEs) containing various types of radiation), from other stars in our galaxy and beyond as gamma rays (from GRBs), ultraviolet and infrared rays, some X-rays, high-speed neutrinos and neutrons, and other particles. Some of the latter strike Earth and all of the life exposed, including humans. However, humans and life in general have evolved and dealt with this radiation, with some periods in geologic history of high radiation causing gene mutations as part of evolving, some life surviving, some being extinguished.

Although the Earth's magnetic shield and atmosphere normally block some of the radiation, some reach the Earth with humans responding by avoiding excessive exposure, or by applying sun-block ointments, etc. As we begin to explore offworld, astronauts also need to be shielded while spending time on the ISS conducting research, and while exploring for life and for minerals of economic interest (uranium, helium-3, thorium, and REE) on the Moon, and on nearby asteroids, the moons of Jupiter (e.g., Europa, etc.), the moons of Saturn (Enceladus) (Titan), and other sites within our solar system.

To investigate how much gamma and neutron radiation reaches humans on Earth, approximately once a week, Spaceweather.com and the students of Earth to Sky Calculus have been releasing space-weather balloons to the stratosphere over California and other states. These balloons are equipped with radiation sensors that detect cosmic rays, a form of space weather. Cosmic rays can seed clouds, trigger lightning, and penetrate commercial airplanes. Furthermore, there are studies (#1, #2, #3, #4) linking cosmic rays with cardiac arrhythmias and sudden cardiac death in the general population. Our latest measurements show that cosmic rays are intensifying, with an increase of more than 18% since 2014 (see Figure 4):

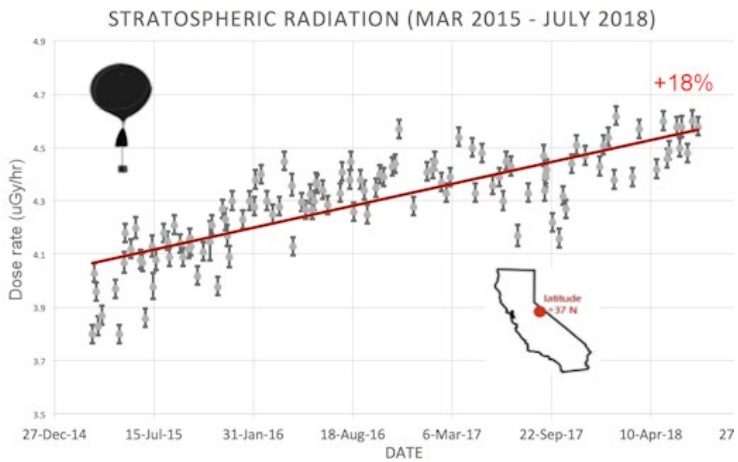

Figure 4 (Spaceweather)

The data points in the graph above correspond to the peak of the Reneger-Pfotzer maximum, which lies about 67,000 feet above central California. When cosmic rays enter the Earth's atmosphere, they produce a spray of secondary particles that is most intense at the entrance to the stratosphere. Physicists Eric Reneger and Georg Pfotzer discovered the maximum using balloons in the 1930s and it is what we are measuring today (see plot: more).

On route to the stratosphere, their sensors also pass through aviation altitudes (see Figure 5) In the plot below, dose rates are expressed as multiples of sea level. For instance, they observed that boarding a plane that flies at an altitude of 25,000 feet exposes passengers to dose rates ~10x higher than sea level (more). At 40,000 feet, the multiplier is closer to 50x. The radiation sensors onboard their helium balloons detect X-rays and gamma-rays in the energy range 10 keV to 20 MeV. These energies span the range of medical X-ray machines and airport security scanners (more).

Cosmic rays are intensifying because of the Sun's reduced output. Solar storm clouds such as coronal mass ejections (CMEs) sweep aside cosmic rays when they pass by Earth. During Solar Maximum, CMEs are abundant and cosmic rays are held at bay. Now, however, the solar cycle is swinging toward Solar Minimum, allowing cosmic rays to return. Another reason could be the weakening of Earth's magnetic field, but this field surrounds Earth and helps to protect us from deep-space cosmic and other radiation (more).

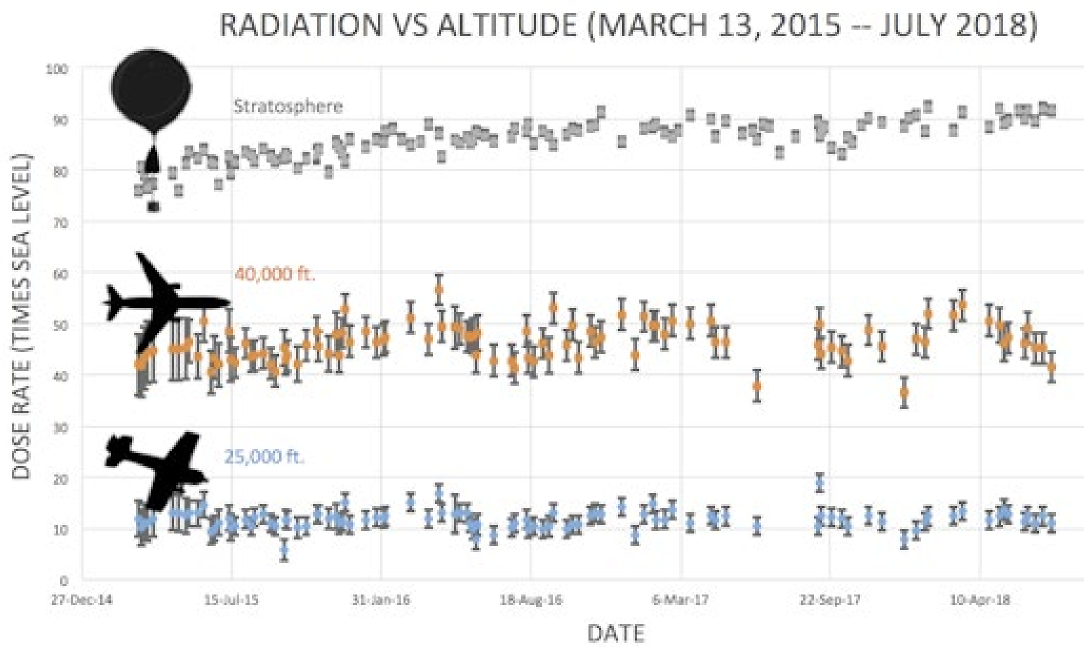

Figure 5 (Spaceweather)

For a dynamic viewing of the northern lights (*Aurora Borealis* aka Earth's magnetic field in action)), see Figure 6, which illustrates a coronal mass ejection (CME) from the Sun, which, but for the magnetic shield, the Earth would be devoid of life as we know it (more).

There continues to be widespread discussions by geologists, geophysics and astronomers regarding the pending magnetic pole reversal and the migration of the north pole from northern Canada toward Russia (more).

Figure 6

Coronal Mass Ejection (CME) Heading for Earth and the Earth's Defense

Also, red lightning has only recently been confirmed in detail above distant thunderheads as momentary flashes, and Smith (2019) caught a group over two big storms in Kansas (see Figure 7). These atmospheric phenomena are termed "sprites" and constitute an exotic form of electricity that appears to shoot up from major storm clouds, instead of down like ordinary lightning.

Figure 7
Observable Sprites over Kansas in 2019.
(Smith, 2019).

Although sprites have been reported for at least a century, many scientists did not believe they existed until after 1989 when sprites were accidentally photographed by researchers from the University of Minnesota and confirmed by video cameras onboard the space shuttle (more).

Smith (2019) has been observing and photographing sprites for years in the stormy U.S. Great Plains around Oklahoma and Kansas. Here are two examples of clusters he caught simultaneously with direct visual observation and camera. The jellyfish shapes he observed had a fiery orange/red color, likely reflecting ionized nitrogen and/or a form of oxygen (ozone?) in the upper atmosphere. The underlying physics of sprites are still not fully understood. Some models hold that cosmic rays help them get started by creating conductive paths in the atmosphere. If cosmic rays do indeed spark sprites, Tony Phillips (2019) suggests that they could be explained because cosmic rays are nearing a Space Age high. See Figure 8 viewing sprites.

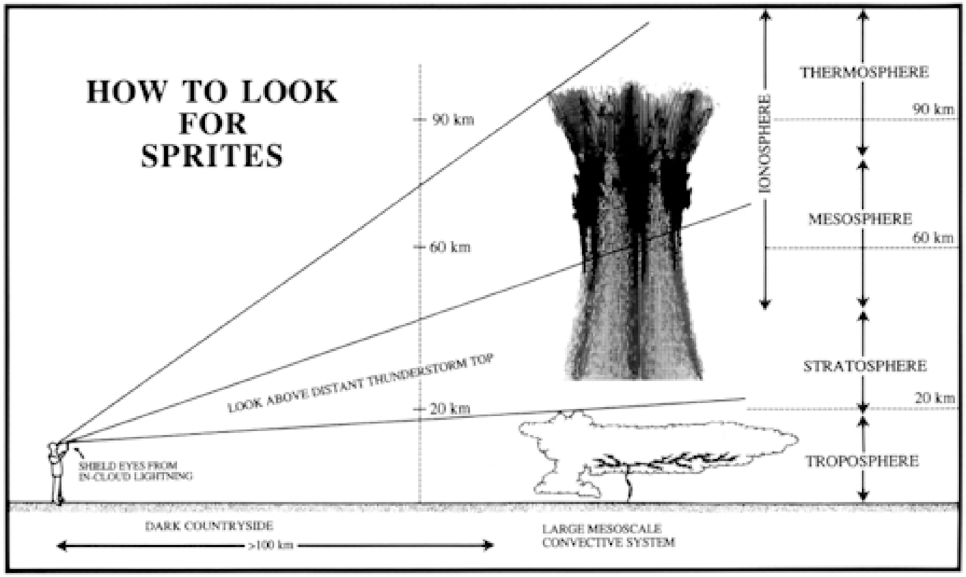

Figure 8 (Smith, 2019)

More examples of sprites may now be found at Smith (2019).

Monitoring for Hazardous Asteroid/Comet Arrivals

After years of prodding by astronomers and others, U.S. government and NASA, JPL, etc. are finally beginning to support and implement a well-funded and meaningful program to monitor asteroids and comets within the orbital reaches of Earth, and to determine what to do if one comes our way (more). CNEOS is NASA's center for computing asteroid and comet orbits and their odds of Earth impact (more).

Human Hazards in Zero Gravity and Orbital and Deep-Space Radiation

Recent medical reports on astronauts returning from long stays in zero gravity on the ISS show that serious damage occurs to brains (more) and tissues (more). This will require rotation and shielding in ships built for space travel and advanced robotics to minimize exposure to astronauts (more). Exposure in near-zero gravity while on bases on the Moon, Mars, Europa, Titan, etc. is currently under intense research. With China forging ahead in the 2nd Space Race, their experiences will no doubt be closely monitored by the U.S., Europe, Japan, Israel, India, and other space-faring nations (more).

Research into all types of known ionizing and other radiation will allow the radiation issues surrounding uranium mining, nuclear power plant operations, and the associated nuclear waste to be placed into the proper perspective of managing any risks involved.

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