EMD Uranium (Nuclear & REE) Committee

2019 EMD Uranium (Nuclear Minerals and REE) Committee Annual Report

May 12, 2019

New Jersey 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 12, 2019

Chairman Presented Summary to EMD Annual Meeting, San Antonio, Texas, May 18th 2019
Report Updated: Version 1.6
(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.,** Pioneer Natural Resources, Midland, TX
 (Founding Member of EMD in 1977, Ex-Tenneco Uranium Inc.)
- **Roger W. Lee, Ph.D., P.G.,** an I2M Associate, 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, Uranium 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 summary 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 February 20, 2019 that included all three Vice-Chairs and appointed members of the UCOM Advisory Group and Special Consultants (see Agenda (here)). 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. The current status of Section 232 was also discussed regarding its possible impact on the U.S. uranium mining industry (more).

On other matters, the AIPG Texas Section has invited UCOM members and members of EMD to join them in sponsoring and participating in a field trip to visit the in-situ uranium mining and processing operations located in south Texas when production resumes (circa 2020-2021). For further information, see the AIPG announcements (more).

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 presented (AAPG Foundation, 2019). We are pleased to announce that Oyeleye Adeboye was awarded the McMurray Memorial Grant in 2019. 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

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 *JNRR 2019 Review on The Unconventional Energy Resources* is under consideration by EMD.

The UCOM Chairman was asked by the EMD EXCOM to assemble a historical account of EMD from its beginning before 1977 to 2018 for publication in AAPG's *The Explorer*. The Chairman is a Founding Member of EMD (1977), Past President of EMD (2010-2011), and has been Chairman of UCOM since 2004. 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 Report Format

UCOM modified the format of the UCOM report a few years ago to provide greater coverage and more timely information in a concise reporting format. To accomplish this, the UCOM members 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, 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 dynamic in nature.

We draw on the I2M Web Portal database, which now contains almost 8,500 abstracts and 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 UCOM (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 of the article(s) cited in the text (which as of this date consist of almost 8,500 records). This provides multiple records of historical development without selection bias. If the search result returned a date-arranged list of summaries, the result will continue to be updated with new entries to the database. The reader can also conduct a multi-word search of the database for related or associated topics of interest (more).

Serving as a summary, the UCOM focus generally covers:

a) **uranium exploration** (more);
b) **uranium mining and processing** (more), and **marketing**,
c) **uranium recovery technology** (more);
d) **nuclear-power economics** (more),
e) **reactor designs** (more),

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

g) **factors affecting plant shutdowns** (more), and

h) **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.

We also monitor, assess, and report 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 thorium concentrates.

Our 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).

The nature and impact of radiation, perceived and real, have been emphasized over the years from a variety of anti-mining and nuclear-power adversaries. In an attempt to educate AAPG members and the general public, we have been addressing these important issues since the beginning in 2004, reporting within the UCOM on their 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). We have updated the section in our recent UCOM reports titled: *Ambient Radiation in the Atmosphere,* near the end of those report. Because the effects of radiation are difficult to put into perspective by many, and even misinterpreted or exaggerated by agenda-driven adversaries, we portray radiation in context with our environment on Earth, in the atmosphere, in the orbital reaches, and in deep space (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 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).

With respect to other environmental issues involved in uranium exploration and mining, we also monitoring asses and report on matters related to radiation in the environment. This is based on the fact that the principal environmental issue 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 movies and news reports of the 1970s and 1980s (more).

Now that we can look back and separate the clear damage done by our use of atomic weapons to end World War II in Japan from 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 in Japan (more). The Chernobyl disaster was in a different class. Because the Soviet Union's expediency 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 fires of the cores. Emergency personnel were rushed into service, which killed more than 30 brave workers (more).

We also now know 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 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 are coming back on-line, driven by the high prices of imported natural gas and by the slow build-up and cost of renewable energy (more).

OBJECTIVES OF UCOM REPORTS

One of the principal objectives of our Annual (Spring) report is to provide a summary of the important developments in uranium exploration and production of yellowcake (U_3O_8) for the benefit of the members of the Energy Minerals Division, AAPG and for the general public who may be interested in how energy is used to generate electricity in the U.S. and overseas.

Another objective is to report on the status of the nuclear power industry worldwide. As the industry expands, the need for fuel will also increase and this will require expansion and development of existing and new sources of uranium.

These activities are driven by nuclear-plant demand for fuel for the 98 reactors currently in operation in the U.S. and the 450 reactors worldwide (and for those under construction/planned for use 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 and 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).

EXECUTIVE SUMMARY

- The U.S. is the world's largest producer of nuclear power, accounting for more than 30% of worldwide nuclear generation of 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 in low-priced natural gas, but two new reactors are being completed in Georgia.
- Following a 30-year period in which few new reactors were built in the U.S., it is expected that two more new units will come online soon after 2020; 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.
- Currently, about 63% of the U.S. electricity generation is from fossil fuels (coal, natural gas, petroleum, and other gases). About 20% was from nuclear energy, and about 17% and rising was from renewable energy sources, including hydroelectric power palnts.
- The first zero-emission credit programs have commenced, in New York, Illinois, and other states.

- ❖ The years 2015 and 2016 exhibited the highest annual growth in nuclear plant capacity in 25 years and has leveled off since at an efficiency of greater than 90%.
- ❖ Significant uranium production cuts were made in 2017 from world's largest uranium producers,
- ❖ Uncovered utility demand reaches ~24% by 2021 and 62% by 2025. Hence, production should resume in the foreseeable future assuming the uranium price continues to rise.
- ❖ Sustained low-price of uranium indicate that few new sources of supply are on-line, but a number of mines are either on stand-by or are available for rapid development,
- ❖ Uranium holdings could be of strategic interest in the event of uranium supply interruption,
- ❖ U.S. utilities looking for risk-free ways to acquire significant supplies for future (likely Canada),
- ❖ Implied current yellowcake value is lower than many mine's cost of production,
- ❖ Most of the uranium purchased by utilities is contracted (based on the long-term price: currently \$32.00/lb U_3O_8),
- ❖ Saudi Arabia plans to build 16 reactors by 2030 with first reactor to come online in 2022;
- ❖ South Korea currently operates 25 reactors providing 33% of South Korea's power, and is building reactors on budget and on time for UAE.
- ❖ Japan is upgrading and re-starting most of its fleet of nuclear power plants after Fukushima.
- ❖ China plans to build 99 reactors by 2030, with government investment of over \$100 billion. Current activities: 38 reactors in operation, 25 under construction, 39 planned/proposed for 240 total reactors on the horizon.
- ❖ China is rapidly building some 25 new plants and hundreds more are planned along with financially underwriting the construction of more than 40 projects in joint ventures with other countries.
- ❖ Russia currently has seven reactors under construction; An average of one large reactor per year is due to come on line through 2028,
- ❖ Russia is testing a "fast breeder" design that consumes most used fuel (waste).

- ❖ Russia is considering banning uranium sales to U.S. utilities because of the sanctions and tariffs applied by the U.S., while Petition 232 is under review to increase domestic mining and limit foreign imports of uranium.

- ❖ Russia also is building a floating nuclear power plant for use along the coast of Siberia and in the Arctic.

- ❖ India has turned to nuclear power to ramp up electricity production to match population growth rates and is also working on "fast breeder" designs.

- ❖ India plans to be 25% nuclear-energy-powered by 2050.

- ❖ Many other countries are also building nuclear plants funded by a variety of sources.

- ❖ There have been numerous discoveries of high-grade uranium deposits in Canada and new low-grade deposits reported to be under development in Argentina and Peru. The main Australian uranium mine in South Australia has resumed operations.

- ❖ Senior U.S. uranium industry personnel indicate that mining in Texas might not be re-initiated for a number of years because of the low uranium prices.

- ❖ Many uranium companies are drilling new and established properties to establish an "in place" resource base in preparation for development sometime in the future as prices begin to rise.

- ❖ A new surficial uranium resource base has been identified in Texas by the U.S. Geological Survey.

- ❖ A new uranium district has been identified in the eastern Seward Peninsula of Alaska encompassed within the eastern margins of McCarthy Basin. Thorium and rare-earth elements have been discovered in the surrounding igneous rocks.

- ❖ New data indicate that based on studies of astronauts, genes in humans are "turned on" in space and remain on after returning to Earth while others return to "normal". The actual impact of these weightlessness studies is still being investigated, but early results from the twin-studies indicate that long-term weightlessness is hazardous to humans, and that rotation creating artificial gravity for long-term space flight will be mandatory.

- ❖ Offworld exploration for uranium and other elements is being supported indirectly by NASA and private space companies to identify distant asteroids and comets for the purpose of adjusting potentially hazardous orbital conflicts with Earth.

- ❖ Ambient radiation on Earth is affected by potential hazards from space and requires monitoring.

- ❖ Research funding on uranium and rare earths, thorium, and rare earths 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 on uranium, and rare earths.

Introduction

The uranium price of the fuel for the nuclear power industry is obviously affected by the economic health of the nuclear power industry in the U.S., at least. The more plants, the higher the demand for fuel from China, India, and other countries. As new uranium supplies from new mines have come on-line but demand has not yet increased as expected, a condition of oversupply continues to persist creating depressed prices, which now shows some potential increase as production has been limited by some large producers, i.e., Kazakhstan (more). The principal impact on current prices is the overhang of uranium supplies remaining in the market (from a lack of consumption) resulting from the slow recovery of nuclear operations in Japan (more) in the period between before the impact of new requirements from China and India, etc. (more). As indicated above, other impacts on the uranium price include the U.S. government, which has been dumping some of their back-up yellowcake supply into the U.S. market (more).

The U.S. government sales more than doubled the expected industry uranium production in 2017, but was suspended in late 2018 (more). in the U.S. However, proceeds from the sale of federal uranium inventory were used to fund the cleanup of legacy federal government nuclear facilities, such as the Paducah and Portsmouth uranium enrichment plant sites. This is an example of the government attempting to pay by bartering for its own activities albeit at the expense of the uranium industry (more).

The current uranium production growth has already been built into the supply chain that has come on-line with ramping up production and this creates an increased amount of uranium to be sold on the basis of the spot price into a weak market, which has been keeping prices low (more). As of late April, 2019, the price remains around \$25.00 to \$30.00 (see Figure 1) as a result of long-term uranium oversupply, although with the Japanese re-starts combined with Chinese and other new reactor start-ups, these activities will serve to diminish the oversupply and serve as a catalyst for rising uranium spot prices along with increasing utility contract prices over the long term.

Figure 1

Historical Spot Price of Uranium: 1988 to 2019 ($/$U_3O_8$)

From (UXC)

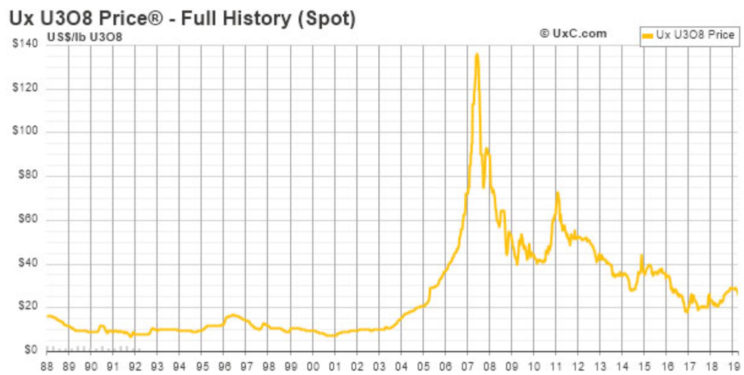
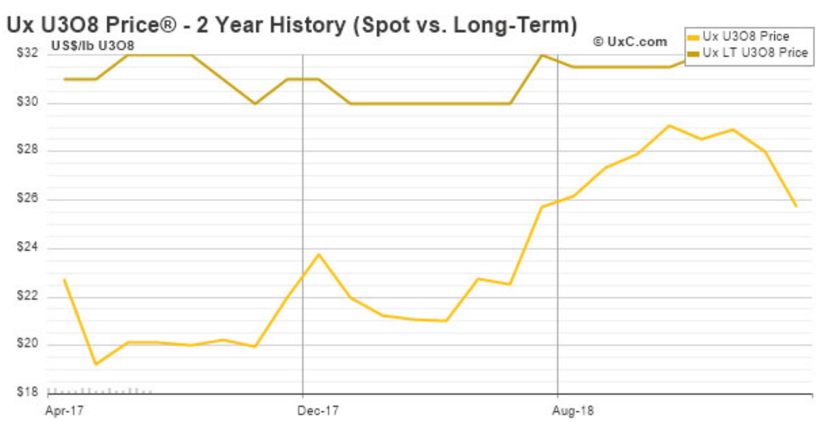


Figure 2 illustrates the recent spot and long-term prices that shows the bottom (and turnaround) of the uranium price has just begun.

Figure 2

Historical Spot and Long-Term Price of Uranium: April 17, 2018 to January 17, 2019 ($/$U_3O_8$)

From (UXC)



However, even with the current low prices, many mining companies are moving forward with uranium exploration and mine-development projects hoping to capitalize on the eventual rebound in prices expected in 2018 or later. The recent uranium spot-price increases involve the perception of supply consumption, which ultimately drives an eventual uranium price bull market, but with early minor price volatility.

The actual fuel price (after conversion of yellow cake (U_3O_8) and refinement into UF6), the precursor is made into the fuel pellets that are assembled in racks during refueling a reactor. The cost of refining the mine-produced yellowcake to the fuel precursor (UF_6) ranges from 2.7 times that of yellowcake during high prices to about 3.0 times during the current low prices of mine-produced yellowcake (more) (see Figure 3 for UF_6 prices).

Even at the current low prices, only 6% of the 57 million pounds U_3O_8 delivered in 2015 was U.S.-origin uranium at a weighted-average contract price of $43.86 per pound (committed to individual utilities). Foreign-origin uranium accounted for the remaining 94% of U.S.-contracted deliveries at a weighted-average contract price of $44.14 per pound U_3O_8. Uranium originating in Kazakhstan, Russia, and Uzbekistan accounted for 37% of the 57 million pounds.

Figure 3
2004 - 2019 UF_6 Fuel Spot Prices ($/kgU)
From (UXC) (for Conversions see (more)

However, the prices have fallen further during the latter part of 2017 with a spot price around $20.00 /pound U_3O_8 and long-term contract prices around $30.00 /pound U_3O_8. Campbell, et al., (2017) discussed the reliance of U.S. uranium fuel needs on foreign sources with a particular emphasis on Russian holdings in the U.S. and elsewhere. More recently, Richards (2018) reports on an appeal by Wyoming uranium producers to the Federal government to limit foreign importing of uranium. In response, Russia is moving to ban trade with U.S. nuclear power plants in response to the new administration's tariff announcements (more).

Industry Response to Current Uranium Prices

During early 2018, the spot price of uranium continued to be relatively stable near the bottom of the cycle (See Figure 2). Significant production cuts were announced in Canada, the United States, Kazakhstan and Africa. The production cuts came after a period of prolonged depressed uranium prices, which, according to UxC, were below the all-in production costs of most of the world's sources of primary uranium supply and coincident with the expected expiration of higher priced supply contracts signed during the utility contracting cycle in the mid-to-late 2000's. Volatility returned to uranium prices late because of these cuts to global production in November 2017 – beginning with Cameco Corporation ("Cameco") announcing a minimum ten-month shutdown of the McArthur River Mine/Key Lake Mill complex in Saskatchewan, Canada.

Cameco's McArthur River/Key Lake operations represent the largest and highest-grade uranium mine in the world, with a designed production rate of approximately 18 million pounds of U_3O_8 annually. Following Cameco's announcement, National Atomic Company Kazatomprom ("Kazatomprom") made a further announcement regarding production restraint – outlining that production through 2020 would represent a 20% reduction in planned output (or more precisely, a 20% reduction from production level defined in the various sub-soil-use contracts) from its operations in Kazakhstan. Following these announcements, the spot price of U_3O_8 increased again, reaching a high of US$26.50 per pound U_3O_8 in December 2017, before retreating to US$21.25 per pound U_3O_8 by the end of fiscal 2018.

Although the Cameco and Kazatomprom supply curtailments have had an impact on the spot price, they have not been sustained. The impact of the curtailments from a global production standpoint, however, is quite significant. According to UxC data, global production peaked in calendar 2016 at 162 million pounds of U_3O_8, then fell in calendar 2017 to 154 million pounds U_3O_8, and this trend continued in calendar 2018 with the latest forecasts of total production dropping to 141 million U_3O_8. To put this in perspective, UxC expects annual uranium reactor requirements (UxC's Requirement's Model "URM" Base Demand) in calendar 2018 to be in the range of 194 million pounds U_3O_8 (more).

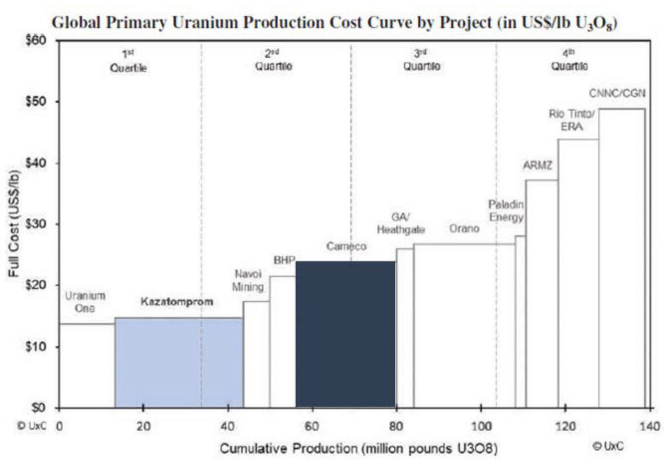
The rationalization on the supply side was long needed, however, because higher-priced, long-term supply contracts were protecting much of the higher-cost mine production from exposure to spot price levels in the US$20 per pound U_3O_8 range that prevailed over the past decade. As many of these legacy contracts are now expiring, the rate and degree of these production resulted in the drawdown of the excess uranium supplies in the market, and more recently in an accelerated rebalancing of uranium market fundamentals, as signaled by most market analysts (more).

Gasebu (2018) provided an overview of the nuclear industry fuel requirements and the role Cameco will likely play in the coming years. Gasebu (2019) also concluded that Cameco is a key player, if not the player, in the global uranium industry. Its reserves and resources (RAR) are slightly more than one billion pounds of uranium or one third of the global reserves than can be extracted at a cost lower than $30 per pound. The company has been supplying an average of 33 million pounds/year of uranium to the market for the last 10 years, equivalent to 20% of the global reactors' fuel requirements. Cameco is not the lowest cost producer (see Figure 4) but is among the three lowest cost producers. Its extraction cost is in the 20-22$/lb. range, and its cash-only extraction cost is in the 11-13$/lb. range. It is also noteworthy that Cameco is the only low-cost producer that is based on a non-government-supported economic structure.

Uranium One is the lowest cost producer. Kazatomprom is the world biggest and lowest cost producer since its mining assets are all operated under ISR technology which is now the most cost-effective extraction method (more). In addition, their operating costs in the country tend to be lower than the operations of Cameco in Canada. Claims by political pundits under the influence of Trump that *Uranium One* controls the U.S. uranium supply is a gross misrepresentation and totally untrue (e.g. as perpetuated by Trump's propaganda group: *FoxNews*). As indicated earlier, the *Uranium One* resources actually controlled were recently reviewed in detail (more) and by the WNA (more).

The next big player is Orano, formerly AREVA, controlled by the French government.

Figure 4



Source: Kazatomprom IPO Prospectus.

The nuclear energy demand is growing, and some upside scenarios are becoming more probable. Current uranium prices cannot sustain production and a cumulative 25% of capacity has been already eliminated.

Cameco's best asset is the **McArthur River Mine**. It's the world's largest, high-grade uranium mine (6.91% grade). It can produce more than 18 million pounds per year by mining only 300 to 400 tons of ore per day. Cameco decided to suspend production for an indeterminate duration. The company share (69.8%) in the reserves of this mine add up to 274 million pounds of reserves or 271 million pounds of U_3O_8 with a recovery factor of 99% reported by the company.

The extracted material is mined at Key Lake mill, the world's largest uranium mill, that is operated by the company with a 83.33% stake in it (more).

Cameco's **Cigar Lake Mine** produces the world's highest-grade uranium ore, with grades (~14.5%) that are 100 times the world average. Cameco owns 50% of the mine and is the mine operator. The mine is currently in operation. Cigar Lake reserves (company share) are 87.5 million pounds. The mine total reported reserves (plus resources) resources, are 149.7 million pounds if we apply the same 99% recovery factor to the reported resources, as reported (more).

The **Inkai Mine** is located in Kazakhstan. The operator is JV Inkai LLP, which Cameco (40%) jointly owns with Kazatomprom (60%). These stakes where recently re-organized to their current levels in early 2018. Cameco's share in this project is 104.6 million pounds in place but given the lower recoverability ratio of 85%, the share amounts to 88.9 million pounds.

The 43-101 reported resources of this project are 42.8 million pounds, equivalent to an additional 36.4 million pounds U_3O_8 when applying the same recovery factor. Therefore, with reserves (plus resources) available from the Inkai Mine, Cameco holds 125.3 million pounds in the project based on the most recent estimate (more).

Cameco is a key player, if not the player, in the uranium industry. The Company's holds about 30% of the global uranium reserves (at a cost to produce of <30$/lb.). Together with Kazatomprom, they account for 55% of the available global low-cost uranium reserves (and that's not including the 43-101 resources).

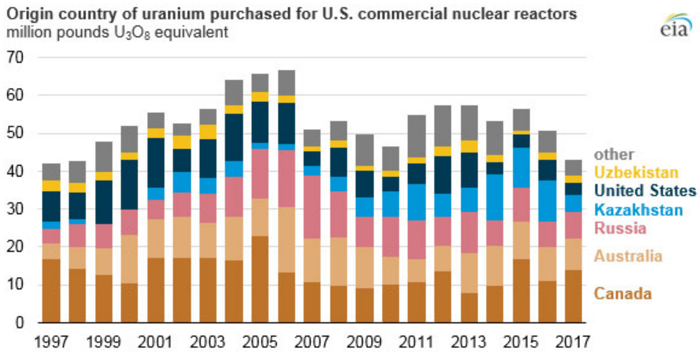
Kazatomprom, the company whose production increase represents 92% of the global production increase since 2007, seems to be following the Cameco leadership after they've become a semi-public company at the end of 2018 (after IPO) and started taking care of their new shareholders. Kazatomprom is now listed on the London Stock Exchange (LSE) and on the Nurs-Sultan International Stock Exchange.

A recent market development that could be preventing the U.S. utilities from entering into a new cycle of significant uranium contracting, is the Section 232 Trade petition filed last year by two U.S. uranium producers before the U.S. Department of Commerce. This provision of the U.S. Trade Act of 1962 was successfully pursued by U.S. producers of aluminum and steel in response to levels of foreign imports that were viewed to be negatively impacting U.S. national security. But Trump has imposed tariffs on the import of both commodities, although some nations (including Canada and Mexico) have been provided exemptions. The petition has passed through the U.S. Department of Commerce to the president for his signature. How he will respond to the uranium Section 232 trade petition, and what (if any) remedies would be applied in the case of uranium imports, is a matter of speculation at this date (more).

For context, U.S. domestically mined uranium accounted for only 5% of U.S. uranium requirements in calendar 2018, and U.S. production has declined further in 2019. Figure 5 illustrate the countries of origin of uranium purchased by U.S. nuclear utilities over the past 20 years. However, as discussed above, with the announcement that Russia could cease selling uranium to American utilities, this action might stimulate American production, but U.S. utilities will likely turn to Canadian and Australian uranium sources to meet demand on the basis of price alone. Russia will likely be marketing their uranium to India and China (more).

If the Section 232 is signed into action, this might stimulate the U.S. uranium mining industry back into production. The U.S. currently has the capability to produce about 25 million pounds U_3O_8 per year, which is at least half of the current U.S. utility requirements.

Figure 5



The trend of increasing nuclear capacity appears to be continuing worldwide (more), and in the U.S. with two under construction and the new technology of SMRs now in the foreseeable future (more). For example, the Chinese government recently announced that in calendar 2018 it would be connecting an additional five reactors to the grid, and that construction will commence on six to eight additional units. In addition, the Kingdom of Saudi Arabia is advancing its nuclear energy plans, having commenced reactor procurement discussions with supplier countries, and the United Arab Emirates is rapidly nearing the completion of their four reactor-construction program, with the first unit expected to be connected to the grid in calendar 2018 (more).

The recovery of the Japanese nuclear energy industry post-Fukushima continued to gain momentum with seven reactors back in operation and a further two more restarted in 2018. This is in line with recently re-elected Japanese Prime Minister Abe's stated goal to utilize nuclear power to supply between 20% and 22% of electricity needs going forward (more), and in planning to displace expensive imported LNG (more).

In the U.S., and despite recent plant closures, production from U.S. nuclear power plants increased about 1% compared with 2017 levels, but still set a record for electricity generation in 2018 (more). The number of total operable nuclear generating units decreased to 98 in September 2018 when the Oyster Creek Nuclear Generating Station in New Jersey was retired (more).

Annual average nuclear capacity factors, which reflect the use of power plants, were slightly higher at 92.6% in 2018 compared with 92.2% in 2017. With the closure of six nuclear power plants in recent years, there has been a growing recognition of the value of the 24/7 baseload, carbon-free energy source. Three states, New York, Illinois and Connecticut, are preserving their nuclear-power generating capacity by passing legislation to level the playing field for nuclear, and three additional states, Pennsylvania, Ohio, and New Jersey, are considering similar legislative action. The U.S. federal government also continues to stress the negative impact on the reliability and resilience of the country's national grid from the potential loss of additional nuclear capacity. A recent Department of Energy Grid Reliability Study and the Federal Energy Regulatory Commission have both pointed to the need for changes to current market structures (more). With respect to new reactor construction in the U.S., the two Vogtle units in Georgia have resumed construction following the Westinghouse bankruptcy restructuring (more), and construction of the two Sumner units in South Carolina remain suspended (more).

In early 2019, WNA reported on the history to date of U.S. electricity production by nuclear power (more). As of August 2018, the World Nuclear Association ("WNA") reported 448 reactors operable worldwide with 57 new reactors under construction, 158 reactors planned or on order, and another 351 proposed. These numbers are, incidentally, higher than those existing prior to Fukushima. Translated into uranium demand, UxC projects their URM Base Demand to range from 174 to 210 million pounds annually over the period from 2018 to 2035 (more).

Global Drivers for Uranium Price Increases

The long-awaited uranium spot-price (and long-term price) increases now have considerable support; the stage for a meaningful turnaround is based on the following historical factors:

- ❖ The years 2015 & 2016 exhibited the highest annual growth in nuclear plant capacity in 25 years.
- ❖ Significant production cuts were made in 2017 from the world's largest uranium producers.
- ❖ Uncovered utility demand reaches ~24% by 2021 and 62% by 2025.
- ❖ Sustained low-prices has limited exploration to a few new sources of supply, but many are available for further economic evaluations and development.

- ❖ Uranium holdings could be of strategic interest to the U.S. and other countries.
- ❖ Utilities looking for risk-free way (aka good deal) to acquire significant supplies for future (likely from Canada and Australia) even though fuel costs constitute less than 10% of the plant operational costs.
- ❖ Recent and current uranium price is lower than many mines' costs of production (see Figure 4.
- ❖ Most of the uranium purchased by utilities is contracted (based on the long-term price: currently at US$32.00/lb U_3O_8), according to Cameco (more).
- ❖ China plans to build 99 reactors by 2030, with government investment of over $100 Billion, Current position: 38 reactors in operation, 20 under construction, 39 planned/proposed for 240 total reactors on the horizon.
- ❖ India plans to be 25% nuclear-energy-powered by 2050.
- ❖ Russia currently has seven reactors under construction; An average of one large reactor per year is due to come on line to 2028.
- ❖ Saudi Arabia plans to build 16 reactors by 2030 with first reactor to come online in 2022.
- ❖ South Korea currently operates 25 reactors providing 33% of South Korea's power, and building reactors on budget and on time for UAE.

Global Drivers for Uranium Production by Mining Company

Russia's Kazatomprom Mines: Announced 20% reduction from permitted production levels for a period of three years commencing January 2018; estimated to represent 7.5% of annual global uranium production (estimated for 2018) in each of the next three years, keeping ~10 million lbs U_3O_8 out of the market in each of 2018, 2019 and 2020. However, the recent issues with the U.S. and the potential Russian ban of sales to U.S. utilities because of sanctions and tariff issues, this will likely alter Russian uranium production cut-backs in order to support an already weak Russian economy.

Cameco: McArthur River/Key Lake Mines to be suspended for 10 months beginning in January 2018; Resulting in an estimated 14-15 million lbs U_3O_8 to be curtailed. These cuts might be reversed if the Russian threat of banning sales to U.S. materializes in order meet U.S. utility requirements.

Areva (now Orano): Somair, Cominak, and Imouraren Mines production cuts of between 13% and 16% lower with further cuts expected. These cuts might be reversed if the Russian threat of banning sales to U.S. materializes in order meet U.S. utility requirements.

Cameco: Rabbit Lake Mine, suspended operations (4 million lbs U_3O_8 /yr); McArthur River Mine reduction (2 million lbs U_3O_8 /yr); U.S. Operations, suspending operations (2.5 million lbs U_3O_8 /yr). These cuts could be reversed if Russian threats of banning sales to U.S. materializes in order meet U.S. utility requirements.

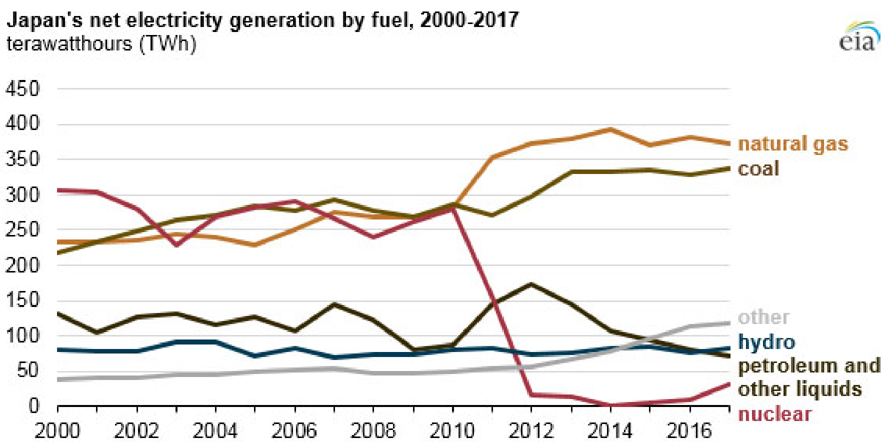
Other Canadian Activities: Mines, Proposed Mines, New Projects.

THE IMPACT OF JAPAN NUCLEAR Re-START-UPS

In response to the 2011 Fukushima accident, Japan suspended operations at all nuclear reactors for mandatory safety inspections and upgrades, leaving the country with no nuclear generation from September 2013 to August 2015. Existing coal-fired power plants were already operating near full load; therefore, utilities had to import large volumes of LNG to meet electricity demand.

Johnson and Zaretskaya, of EIA (2019), report that in 2018, Japan restarted five nuclear reactors that were shut down after the 2011 incident. Nuclear power generation in Japan represented about 27% of the power generation prior to the 2011 earthquake, and it was one of the country's least expensive sources of electric power (more). As those reactors return to full operation, the resulting increase in nuclear generation is likely to displace generation from fossil sources, in particular natural gas. Because Japan imports all of its natural gas in the form of liquefied natural gas (LNG), increased nuclear power production is likely to reduce Japanese imports of LNG in the electric power sector by as much as 10% in 2019 , see Figure 6.

Figure 6

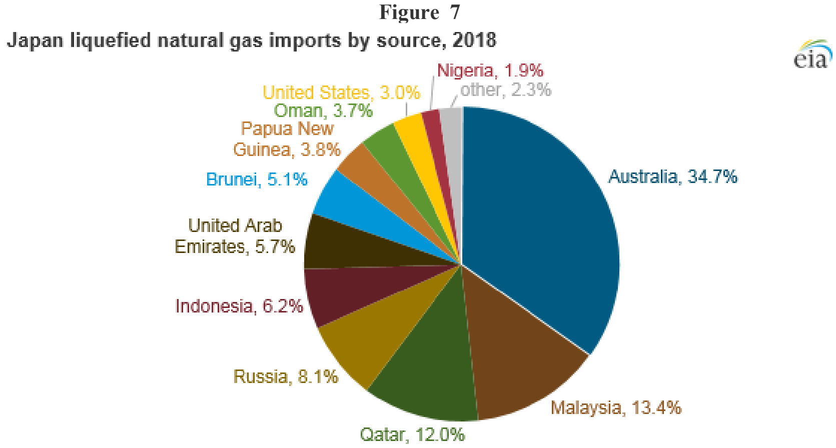


Japan now has nine operating nuclear units with a total electricity generation capacity of 8.7 gigawatts. Electricity generation produced by natural gas-fired plants in Japan has been declining annually from its peak in 2014 and will decline further in 2019, while generation from nuclear power plant output will likely increase as the safety-reviewed plants come on-line (i.e., as all plants are outfitted with improved back-up power systems).

As the five nuclear reactors were gradually restarted in 2018, they began to offset natural gas-fired generation, and as a result, LNG imports decreased as the reactors reached full operation. In 2019, their first full year of operation, EIA estimates that the restarted nuclear reactors will further displace Japan's LNG imports by about 5 million metric tons per year (MMmt/y), or 0.7 billion cubic feet per day (Bcf/d) of LNG. This amount is equivalent to 10% of Japan's power sector natural gas consumption and 6% of Japan's LNG imports in 2018.

Consumption of crude oil and petroleum products by power plants also increased between 2011 and 2013, with utilities spending about $30 billion each year for additional fossil fuel imports in the three years following the Fukushima earthquake and associated power plant loss of back-up power at one of the major nuclear power plants. Generation from crude oil and petroleum products returned to pre-Fukushima levels by 2014 mainly as a result of relatively high crude oil prices, and it has since declined further.

Figure 7



Source: U.S. Energy Information Administration, Japan Ministry of Finance
Note: Other includes Angola, Egypt, Equatorial Guinea, France, Spain, Netherlands, Peru, South Korea, Singapore, and Trinidad.

Japan relies on imported LNG to meet all of its natural gas demand and imports more LNG than any country, averaging 11 Bcf/d in 2016 through 2018. Japan imports LNG from several countries worldwide (see Figure 7). LNG imports from Australia have grown in the past two years to account for more than one-third of the total imports, and they have displaced imports primarily from Malaysia and Qatar. In 2016 through 2018, these three suppliers accounted for 60% of Japan's LNG imports.

The outlook for further LNG import displacement is largely dependent on the number of nuclear plant restarts, assuming anticipated trends in other factors, such as electricity demand and energy efficiency, remain constant. The pace of nuclear restarts has been slow, with the average reactor requiring nearly four years to come back online (more).

Japan's long-term energy policy calls for the nuclear share of total electricity generation to reach 20% to 22% by 2030, which would require up to 30 reactors to be in operation (more). Out of the remaining fleet of 35 operable reactors, 9 are currently operating, 6 have received initial approval from Japan's Nuclear Regulation Authority, 12 are under review, and 8 have yet to file a restart application (for an update: more).

URANIUM PRODUCTION IN THE U.S.

First Quarter of 2019

U.S. production of uranium concentrate (U_3O_8) in the first quarter of 2019 was 58,481 pounds, down 83% from the fourth quarter of 2018 and down 74% from the first quarter of 2018. During the first quarter of 2019, U.S. uranium was produced at four U.S. uranium facilities, two fewer than in the fourth quarter of 2018.

U.S. Uranium In-Situ Leach Plants in Production (state)

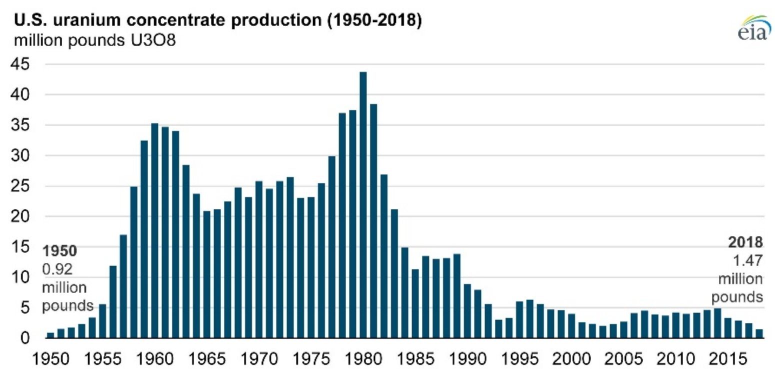
1. Lost Creek Project (Wyoming)
2. Nichols Ranch ISR Project (Wyoming)
3. Ross CPP (Wyoming)
4. Smith Ranch-Highland Operation (Wyoming)

Total 2018 U.S. Production

Total preliminary U.S. uranium concentrate production totaled 1,466,500 pounds U_3O_8 in 2018. This amount was 6% lower than the 2,443,000 pounds produced in 2017 and the lowest annual U.S. production since 2,282,400 pounds U_3O_8 were produced in 2004. A high of 6,321,000 pounds was produced in 1996 (see Figure 8). Production reflects primary source uranium from the 4 operating in-situ leach facilities as well as primary, alternate and recycled feed at the White Mesa Mill in Utah (see EIA, 2019)

White Mesa Mill, owned and operated by Energy Fuels Inc., released additional information on the mill's operations in its financial filings, including the amount of U_3O_8 produced from alternative feeds. The company's financial filings are, at this writing, are available (here).

Figure 8



The status of the in-situ recovery plants in the U.S. are presented in Table 2. Notice that there are 19 such facilities in various states of readiness in 2017, but according to EIA (2019) this number has dropped to 4, although the others would still be available for re-starts given new production from the mining facilities in Wyoming, Utah, Texas, and New Mexico (more).

Uranium Exploration

The nuclear fuel cycle starts with exploration for uranium and the development of mines to extract the uranium ore, usually produced as U_3O_8, which is only slightly radioactive. A variety of techniques are used to locate uranium, such as airborne radiometric surveys, hydrochemical sampling of groundwater and geochemical sampling of rocks, sediment and soil horizons, and as exploratory drilling to characterize the underlying geology (see Campbell and Biddle (1977)). Once significant uranium mineralization is located, the mining company follows up with more closely spaced development drilling, to determine how much uranium is available and what it might cost to recover it (see Dickinson and Duval (1977) and Campbell, et al., 2007).

No new uranium discoveries have been made in the U.S., other than the major hardrock discovery in southern Virginia (which would be mined by open-pit) (more): 1) the surficial (calcrete) uranium discovered by the U.S. Geological Survey in Texas (more), and 2) the discoveries made as a result of the work done by Campbell, Rackley *et al*. on the eastern Seward Peninsula (Alaska) of hardrock uranium, thorium, and REEs occurrences, but even more important was their recognition of a potential new uranium district in the Tertiary McCarthy Basin created by a possible 35-mile diameter impact crater sometime in the early to mid-Cretaceous period (more).

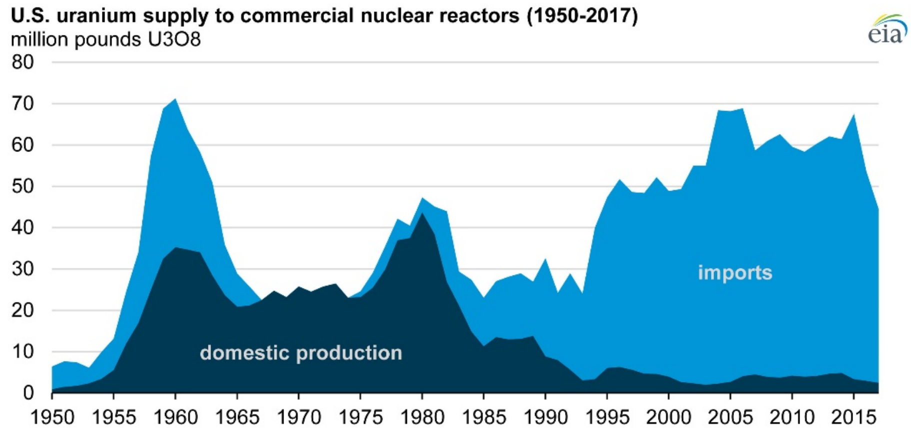
The Tertiary basin exhibits all the geological prerequisites (e.g., presence of lignite, arkosic sands, source rocks containing leachable uranium along the eastern margin of basin, and the reported presence of high-grade roll-front uranium mineralization in small, fault-bound associated basins just to the east of McCarthy Basin (more)) combining to contain multiple sedimentary "roll-front' deposits of probable economic interest, even in the generally harsh weather and remote location of the basin, which may be no worse than those features occurring in Montana and Wyoming in the winter months.

Uranium Mining in the U.S. and Worldwide

WNA reports that the U.S. ranks 15th in the world for known uranium resources in the category up to \$130/kgU (\$50/lb U_3O_8), with 47,200 tU (roughly equivalent to 94 million pounds U_3O_8 as produced) (reasonably assured resources, 2017), or about 1% of world total of about 9.4 billion pounds of U_3O_8 in place. EIA (2018) estimates of U.S. resources are meaningless because many companies do not release resource estimates and are hence not included (more), with updates.

In the late 1950s, the U.S. had a great deal of uranium mining, promoted by federal subsidies. Peak production since 1970 was 16,800 tU (~ 34 million pounds) in 1980, when there were over 250 mines in operation in the U.S. This abruptly dropped to 50 in 1984 (as a direct result of Three-Mile Island incident in 1979 and followed a few years later by Chernobyl accident when only 5,700 tU (~11 million pounds U_3O_8) were produced, after which there was a steady decline to 2003, when there were only two small U.S. operations producing a total of under 1,000 tU/yr (~2 million pounds), or about 5% of the uranium consumed by U.S. nuclear plants (see Figure 8A). U.S. has been relying on imports of uranium from countries such as Canada and Australia, and others (or in the form as downblended weapons-grade uranium from Russia until 2013 when that program ended (see section on military surplus and other government stocks (more)).

Figure 8A



Worldwide, uranium mines operate in some 20 countries, though in 2017 some 53% of world production came from just ten mines in four countries with these four countries providing 71% of the world's mined uranium (see list of mines (more)).

These mines have been discussed in some detail earlier in this report, but most of the uranium ore deposits at present supporting these mines have average grades in excess of 0.10% of uranium – that is, greater than 1,000 parts per million. In the first phase of uranium mining to the 1960s, this would have been seen as an acceptable grade, but today some Canadian mines have huge amounts of ore up to 20% U_3O_8 average grade, so high that robotic mining and handling of the ore in the underground mines will likely be undertaken to reduce radiation exposure to miners, which will certainly drive the up the cost of production. Other mines, however, can operate successfully with very low grade ores, down to about 0.02% U_3O_8, although mining economics involving the cost to produce and the uranium price are limiting factors (more).

Some uranium and rare earths also can be recovered as a by-product with copper, as at Olympic Dam mine in Australia, or as by-product from the treatment of other ores, such as the gold-bearing ores of South Africa, or from phosphate deposits such as Morocco and Florida (more). In these cases, the concentration of uranium and rare earths may be as low as a tenth of that in orebodies mined primarily for their uranium content.

As indicated above, it should be noted here that an "orebody" is defined as a mineral deposit from which the mineral may be recovered at a cost that is economically viable given the current market conditions. Where a deposit holds a significant concentration of two or more valuable minerals then the cost of recovering each individual mineral is reduced as certain mining and treatment requirements can be shared. In this case, lower concentrations of uranium than usual could be recovered at a competitive cost in many projects.

U.S. Nuclear Power Plants Under Construction

The construction of the first two AP1000 units is well underway at Vogtle, Georgia, with about and is expected to go online (more). The V. C. Summer nuclear plant has been operational for some time (more). Construction was also well underway at Summer, South Carolina, but that has been put on hold. In addition to the sites above, Southern Company is evaluating several possible sites, including existing plant sites and greenfield locations, for additional AP1000 reactors (more). However the economic outlook since 2013-14 indicates that merchant plants are not economically viable, and that some kind of assured market is necessary to underwrite the high-capital costs of nuclear plants (more).

U.S. Small Modular Reactors (SMRs)

New reactor designs are being certified but not yet marketed in the U.S. (more). Small modular reactors (SMRs), are on a fast-track for certification and marketing in the U.S., UK, Middle East, China and elsewhere (more). In addition, several designs of small modular reactors (SMRs) are proceeding towards NRC design certification application or the alternative two-step route of a construction permit then operating license. As indicated in our 2018 Mid-Year UCOM report, it would be appropriate to update the following activities:

- A demonstration unit of the 160 MWe Holtec SMR-160 PWR (with external steam generator) is proposed at Savannah River Plant with DOE support, and a construction permit application is likely, or a similar application in Canada. In September 2016 Mitsubishi Electric Power Products and its Japanese parent became a partner in the project, to undertake the I&C design and help with licensing. In 2017, SNC-Lavalin joined the project. South Carolina and NuHub also backed the proposal and it should move forward (Update).

- A demonstration unit of the NuScale multi-application small reactor, a 50 MWe integral PWR is planned for the Idaho National Laboratory. Subsequent deployment of 12-module power plants in western states is envisaged under the Western Initiative for Nuclear. The NRC accepted NuScale's design certification application in 2017 and a COL application is planned early in 2018. Nuscale had spent some $170 million on licensing to mid-2015, and expects the NRC review to take 40 months, with the first unit operating in the mid-2020s.

In 2013 NuScale secured up to $226 million DOE support for the design, and applied for the second part of its loan guarantee in September 2017. Further details under the section on UAMPS below (Update).

- SCEG is evaluating the potential of X-energy's Xe-100 pebble-bed SMR (50 MWe, a high temperature gas-cooled reactor) to replace coal-fired plants, in 200 MWe 'four-pack' installations (Update).

- In August 2015, Russia's AKME-Engineering received a US patent for its modular SVBR -100 lead-bismuth cooled integral fast reactor. The company said that it wants to protect its intellectual property as it prepares for the construction of a prototype SVBR-100 unit at Dimitrovgrad. No plans for the U.S. have been announced (Update).

In 2014, the NRC said that its most optimistic scenario for awarding design certification for small reactors such as SMRs was 41 months, assuming they were light water types (PWR or BWR). Since then, however, as indicated above, SMR development seems to be picking up momentum in the U.S., U.K., and, of course, China (more).

Nuclear Used Fuel (Waste) Storage

The debate continues in the U.S. on when and where to store the nuclear waste material generated by 98 nuclear power plants in the U.S. (more). The new administration was pressing for the Yucca Mountain facility to be completed after spending billions of dollars on its development to date. However, alternatives are also being considered. Conca (2018) reports that the U.S. Nuclear Regulatory Commission has accepted Holtec International's license application for its proposed consolidated interim storage facility for spent nuclear fuel (more), called HI-STORE CIS (more). To be located in southeastern New Mexico near Carlsbad, the facility would store spent nuclear fuel, (which is referred to as "slightly used" nuclear fuel), until a final storage facility is built or until new fast reactors are available that will recycle it into new fuel and minor volumes of actual waste.

For perspective, reactor fuel usually spends five years in the reactor, after which about 5% of the energy in the fuel is used. However, fission by-products of the reactions have built-up to the point where the fuel must be replaced. After the fuel assembly is withdrawn from the reactor, the spent fuel usually spends about 5 years in spent-fuel pools of water (similar pool systems that lost back-up power supplies circulating water and exposing the fuel (aka "core") after the Fukushima earthquake), until heat and radiation have decreased sufficiently to allow the fuel to be passively cooled in a dry cask. These systems are a temporary interim measure. The stainless-steel canisters are easily retrievable and ready for transport whenever a storage solution is chosen, such as deep geologic storage or burning in fast reactors. The canisters are designed, qualified, and tested to survive for centuries and prevent the release of radioactive material under adverse accident scenarios postulated by NRC regulations for both storage and transportation (more).

As an add-on, Holtec is also seeking approval from NRC to use the heat generated by the waste, from just sitting on the pad, to drive systems to process drinking water from dark water contained in industrial processes like drilling to remove metals and organics. New Mexico generates volumes of water contaminated with organics and salts, especially in the region where the interim nuclear waste storage facility will be located, and use of Holtec's patented process-heat design may assist this arid region in optimizing waster resources (more).

Even though the 'store in place" plan is viable, the nuclear power plants have been paying for decades, as mandated by law, for a secure place to store (not dispose) the nuclear waste generated by the nation's nuclear power plants (more). This distinction has been made on the basis that the material could be useful at some point in the future for reprocessing.

The activities of the growing support and the opposition against opening the Yucca Mountain facility is being continuously monitored by the I2M Web Portal (more). In all, billions of dollars have been collected by the federal government to manage the nuclear waste, but the completion of the Yucca Mountain Facility has been blocked by anti-nuclear opponents (and congressmen), including a few senators (more), so other sites are now being considered (more). Conca (2018) suggests that a new site near Carlsbad might be feasible.

Australia has also begun to evaluate the feasibility of offering nuclear waste storage services to the world (more); whether this will develop into an actual service remains to be seen because there are also anti-nuclear adversaries in Australia as well as in the U.S. and elsewhere. The current status of nuclear waste storage and associated topics is available (here).

INTERNATIONAL URANIUM EXPLORATION AND DEVELOPMENT

Contrary to the exploration and mining projects in the U.S., drilling in Canada is at record levels, primarily because of the world-class discoveries that are being developed in the Athabasca Basin over the past few years. UCOM reports have discussed these in some depth (more). Drilling is also very active in Kazakhstan, in Africa, and South America, China, and Australia. Although the latter has substantial uranium potential, it is still suffering from political fatigue in all uranium states (Western Australia, Northern Territory, Queensland, and even South Australia).

In response to the expansion in plant construction throughout the world, new discoveries of uranium deposits in Canada and elsewhere have increased in number over the past decade even under conditions of low market prices for U_3O_8. This continuing activity has occurred no doubt as a result of increasing confidence that nuclear power will continue to expand worldwide (and U.S.) to support the future demand for uranium.

As indicated above, exploration in Canada has produced numerous discoveries, many of which are of world-class deposits located around the periphery of the Athabasca Basin of Saskatchewan , see Figure 9 (more).

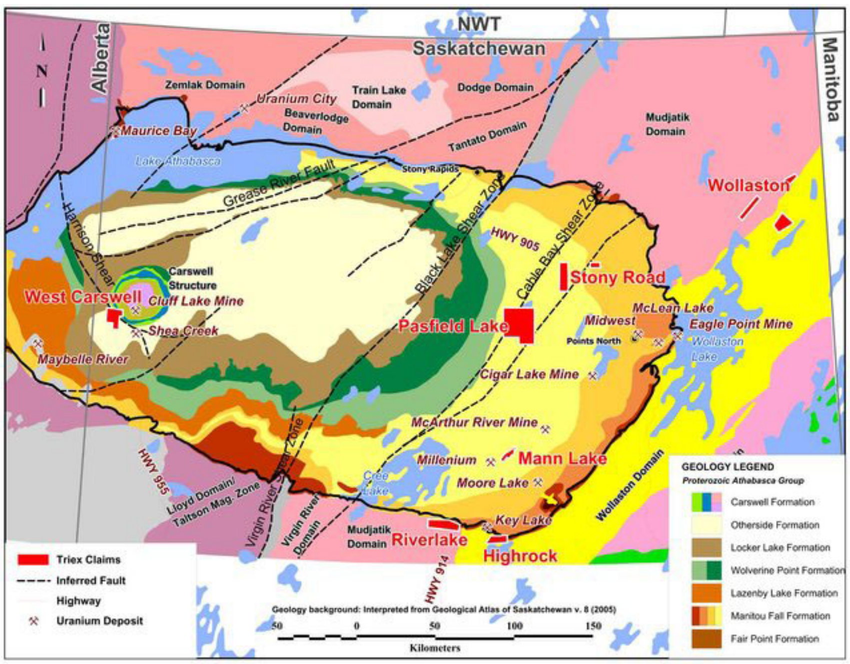


Figure 9 - Athabasca Basin and Associated Uranium Mines

Specifically, NexGen is drilling up huge reserves with high uranium grades at depth (more), while Fission has made another major discovery in the Patterson Lake area (more), and UEX continues to expand its reserve base at Christie Lake with a wide zone with high grades of uranium mineralization (more). The top 10 mines are located in: Canada (more than 1 mine), Kazakhstan (5 mines), Australia (1 mine and others), Niger (1 mine and others), Russia (1 mine and others), and Nambia (1 mine and others). The World Nuclear Association also just published an update for the rest of the world (more).

INTERNATIONAL URANIUM PRODUCTION

As indicated previously, the U.S. consumes a significant portion of the world's uranium supplies for use as fuel to create electricity by nuclear power (fission), yet it produces only a few million pounds of this raw material to make fuel inside the U.S. (2016). As indicted in the 2018 UCOM report, the U.S. government continues to make an effort to focus on energy independence, and there will likely be a push to potentially subsidize production of uranium by U.S uranium companies (or production by a U.S. or Canadian companies operating outside the U.S., e.g., the URI (now Westwater Resources') Temrezli Uranium Project in Turkey, the UEC's Oviedo Uranium Project in Paraguay, and Macusani in Peru, etc.) in order to avoid reliance on importing uranium to supply power plants by unreliable foreign-owned uranium mining companies. If that situation were to occur, a number of projects in the U.S. that are currently not economically viable would be brought on-line for immediate evaluation and preparation for mining and production of uranium.

With more than 450 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 2017) is 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 other areas have been shown to have such expansion capabilities, e.g., Cigar Lake, McArthur River in Canada. But new, large deposits (some very high grade) have been discovered nearby around the rim of the Athabasca Basin of Saskatchewan and Manitoba, Canada, breccia pipe deposits in Arizona (more), and roll-front deposits elsewhere in the world (i.e., Peru, Uruguay and Paraguay, India, Iran, and Tanzania. World nuclear power plant requirements for 2017 was indicated at 65 million tonnes (or 130 million pounds U_3O_8: (more), the difference was made up from the U_3O_8 held by utilities, dealers, and governments.

Based on the top mines, plus the new discoveries in Canada, South America and others to be made, there will be no shortage of fuel supplies from producing mines over the next few decades at least, and from the new anticipated production (more). But, this might even create market conditions that will keep the price below $75.00 per pound ($U_3O_8$). As indicated to date, 35 countries account for about 5 million tonnes of U_3O_8 in the ground (equivalent to about 10 billion pounds U_3O_8), which would provide utilities with fuel for some 80 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).

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 discoveries to support the development of these high-grade deposits (more), including the Chinese buying into mines in Canada (more) and in Namibia (more), and mine development 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 (see Figure 10).

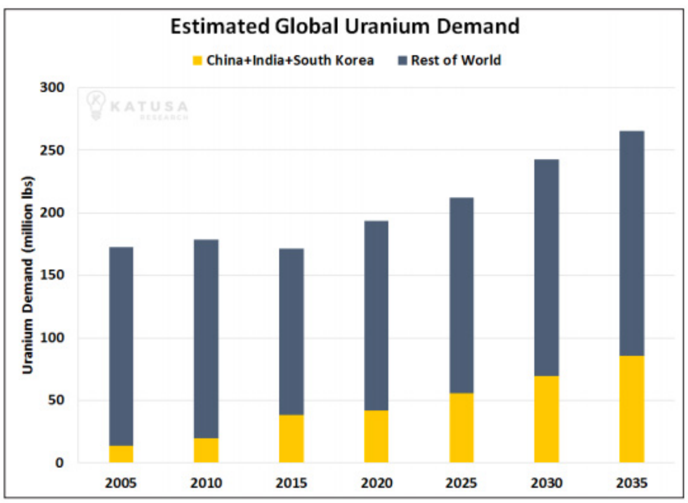


Figure 10
(Shaw, 2017)

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).

FUEL COMPETITION

Updated citations topical issues:

1. Coal vs. Nuclear Power and Natural Gas (here)
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 reactor development to date (more).

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 earthquake and damage occurred at the Daiichi plant in 2011 with very few grants and new sources for funding. Interest in Rare Earth Elements [REE] research has not been a popular subject of research but this should be changing with the industrial research being carried out on the new sources of REE discovered in west Texas and in U.S. coal. Lack of career opportunities in the uranium and REE mining might also be a factor in the lack of student interest in pursuing research related to uranium and rare earths, but the recent discovery of deep sea-floor rare earths and other metals continue to be investigated for their economic and environmental feasibility (more).

The sea-floor deposits are located near the island of Minami-Torishima, about 1,900 km southeast of Tokyo. The research team, led by Yutaro Takaya, an instructor at Waseda University and Professor Yasuhiro Kato of the University of Tokyo, published detailed findings on the size of the deposits for the first time in *Scientific Reports*, a U.K. online scientific journal. They also said they had come up with the technology to allow the resources to be extracted efficiently even from such great depths and with minimal environmental disturbance. The researchers plan to work with private companies to recover the rare earths (more).

The Society of Economic Geologists Foundation (SEGF) and the SEG Canada Foundation (SEGCF) recently announced the Student Research Grant awards for 2018. These grants will 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 53 grants awarded, there was only one award for uranium research, and none were related to REE deposits. The one award was by the Society of Economic Geologists Canada Foundation (SEGCF) which supports innovative research and education in economic geology, currently with an emphasis on supporting Canadian students, and/or studies at Canadian institutions. The SEGF research award was on an Athabasca Basin project:

Canada Foundation SEGCF

Dillon Johnstone	US$4,500	University of Regina (Canada)	Ph.D.	The lithological and structural evolution of the Patterson Lake corridor, SW Athabasca Basin, Canada: Host to a world-class uranium system.

Colorado School of Mines

John DeDecker, a Ph.D. student at the Colorado School of Mines, is working on unconformity related uranium deposits in the Athabasca Basin and has published the following two abstracts with T. Monecke:

DeDecker, J., Moneke, T., 2018. The Fox Lake unconformity-related uranium deposit: Athabasca Basin: Paragenesis of alteration minerals and possible implications to ore deposition. Society of Economic Geologists 2018 Conference. Keystone, Colorado 22-25 September 2018. Conference Proceedings. 200.

DeDecker, J., Monecke, T., Zaluski, G., 2018. Chlorite alteration of pre-ore pyrite at the McArthur River uranium deposit, Athabasca Basin: Publication List - Thomas Monecke Page 12 Paragenesis and possible implications to ore deposition. Society of Economic Geologists 2018 Conference. Keystone, Colorado 22-25 September 2018. Conference Proceedings.

Alexander Gysi, assistant professor at Colorado School of Mines, has produced breakthrough research on the partitioning behavior of REE between fluids and minerals in ore deposits. Dr. Gysi has published 4 peer-reviewed articles on REE chemistry in ore deposits:

Gysi A.P., Harlov D., Miron, D. (2018) The solubility of monazite (CePO4), SmPO4, and GdPO4 in aqueous solutions from 100 to 250 °C. Geochimica et Cosmochimica Acta 242, 143-164. https://doi.org/10.1016/j.gca.2018.08.038

Perry E., Gysi A.P. (2018) Rare Earth Elements in Mineral Deposits: Speciation in Hydrothermal Fluids and Partitioning in Calcite. Geofluids 89, 581-596. https://doi. org/10.1155/2018/5382480P

Pierre S., Gysi A.P., Monecke, T. (2018) Fluid chemistry of mid-ocean ridge hydro-thermal vents: A comparison between nu-merical modeling and vent geochemical data. Geofluids 2018. https://doi.org/10.1155/2018/1389379

Hurtig N., Hanley J., Gysi A.P. (2018) The role of hydrocarbons in Pillara Mississippi Valley-Type Zn-Pb ore formation, Canning Basin, Western Australia. Ore Geology Reviews 102, 875-893. https://doi.org/10.1016/j.oregeorev.2018.09.012

New Mexico Institute of Mining and Technology

Virginia McLemore at New Mexico Institute of Mining and Technology has been very active in uranium and REE research and has provided a list of publications and abstracts published in 2018:

Papers:

McLemore, V.T., 2018, Rare Earth Elements (REE) Deposits Associated with Great Plain Margin Deposits (Alkaline-Related), Southwestern United States and Eastern Mexico: Resources, 7(1), 8; 44 p., doi:10.3390/resources7010008; http://www.mdpi.com/2079-9276/7/1/8 link http://www.mdpi.com/2079-9276/7/1/8 (international publication)

McLemore, V.T., 2018, Mineral-Resource Potential of proposed U.S. Bureau of Land Management exchange of lands with New Mexico State Land Office: New Mexico Bureau of Geology and Mineral Resources, Open-file Report OF-598, 152 p. https://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=598

McLemore, V.T., 2018, Mineral-Resource Potential of Sabinoso Wilderness Area and Rio Grande Del Norte National Monument in Northeastern New Mexico: New Mexico Bureau of Geology and Mineral Resources, Open-file Report OF 599, 55 p. https://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=59

McLemore, V.T., Smith, A., Riggins, A.M., Dunbar, N., Frempong, K.B., and Heizler, M.T., 2018, Characterization and origin of episyenites in the southern Caballo Mountains, Sierra County, New

Mexico: New Mexico Geological Society, Guidebook 69, p. 207-216.

Abstracts:

Caldwell, Samantha;Chavez, William X, 2018, Paragenesis of uranium minerals in the grants mineral belt, New Mexico: applied geochemistry and the development of oxidized uranium mineralization, in: 2018 New Mexico Geological Society Annual Spring Meeting, April 13, 2018, Macey Center, New Mexico Tech campus, Socorro, NM, Timmons, Stacy, ed(s), pp. 21.

Griego, Tylee M.;Campen, Matt;Lewis, Johnnye;Brearley, Adrian J., 2018, Airborne health hazards on Native American Tribal Lands: the uranium mining legacy, in: 2018 New Mexico Geological SocietyAnnual Spring Meeting, April 13, 2018, Macey Center, New Mexico Tech campus, Socorro, NM,Timmons, Stacy, ed(s), pp. 32.

Kicker, Chase;Frolova, Liliya;Rogelj, Snezna, 2018, New inorganic-organic carbon-based hybrid material for selective uranium capture, in: 2018 New Mexico Geological Society Annual Spring Meeting, April 13, 2018, Macey Center, New Mexico Tech campus, Socorro, NM, Timmons, Stacy, ed(s), pp. 40.

McLemore, V.T., 2018, Critical minerals and Abandoned Mines (AML) in New Mexico; in McLemore, V.T. and Frey, B., editors, 2018, Making Abandoned Mine Lands (AML) Profitable—Workshop Proceedings and Abstracts: New Mexico Bureau of Geology and Mineral Resources, Open-file Report OF-597, p. 24, https://geoinfo.nmt.edu/publications/openfile/downloads/500-599/597/Presentations/IWG_OralPresentations/4-McLemore18AMLwks.pdf

McLemore, V.T., 2018, Gold and Rare Earth Elements (REE) Deposits associated with Great Plain Margin Deposits (alkaline-related), Southwestern United States and Eastern Mexico (abstr.): Geological Society of America Rocky Mountain Section, Flagstaff, https://gsa.confex.com/gsa/2018RM/meetingapp.cgi/Paper/314062

Rämö, O. Tapan, Calzia, James P., and McLemore, Virginia T., 2018, Evolution of southern Laurentian Lithosphere; Some New Observations From Crustal Domains and Mid-Proterozoic Alkaline Magmatic Suites in Mojavia And Mazatzal (abstr.): Geological Society of America Rocky Mountain Section, Flagstaff, https://gsa.confex.com/gsa/2018RM/meetingapp.cgi/Paper/314029

McLemore, V.T., Adam Smith, A., Riggins, A.M., Dunbar, N., Heizler, M.T., and Tapani Rämö, T., 2018, Characterization and origin of the REE-bearing Cambrian-Ordovician episyenites and carbonatites in southern and central New Mexico, USA: SEG (Society of Economic Geologists) 2018: Metals, Minerals, and Society, Keystone, Co, September, poster, http://www.segabstracts.org/schedule_public.php
.
McLemore, V.T., Silva, M., Asafo-Akowuah, J., Frey, F., 2018, Chemical variations among particle size fractions: examples from uranium deposits in New Mexico, USA (abstr.): Geological Society of America Annual Meeting, Indianapolis, Indiana, Geological Society of America Abstracts with Programs. Vol. 50, No. 6, ISSN 0016-7592, https://gsa.confex.com/gsa/2018AM/meetingapp.cgi/Paper/321564

McLemore, V.T., 2018, Mineral-resource potential in New Mexico (abstr.); Geological Society of America Annual Meeting, Indianapolis, Indiana, Geological Society of America Abstracts with Programs. Vol. 50, No. 6, ISSN 0016-7592, https://gsa.confex.com/gsa/2018AM/webprogram/Paper317524.html

Frey, B.A., Cadol, D., McLemore, V.T., Chávez Jr., W.X., Hettiarachchi, E., Brown, R.D., Caldwell, S., Pearce, A.R., Asafo-Akowuah, J. and Silva, M., 2018, Examining uranium transport, sources and waste in New Mexico mining districts (abstr.): Geological Society of America Annual Meeting, Indianapolis, Indiana, Geological Society of America Abstracts with Programs. Vol. 50, No. 6, ISSN 0016-7592, https://gsa.confex.com/gsa/2018AM/webprogram/Paper320624.html

McLemore, V.T., 2018, Mineral-resource potential in New Mexico (abstr.): American Exploration and Mining Association, annual meeting, December.

McLemore, V.T., 2018, Uranium in the Grants Mineral Belt – Ore Formation, Mining Techniques, Processing, Economics: National Abandoned Uranium Mines Working Group meeting, Albuquerque, November, http://geoinfo.nmt.edu/staff/mclemore/documents/mclemore_blm18.pdf

University of Texas at Austin

Brent Elliot at the University of Texas at Austin has studied the REE occurrences in the Trans Pecos area of Texas and published a paper on the Round Top REE deposit:

Elliott, B. A., 2018, Petrogenesis of heavy rare earth element enriched rhyolite: source and magmatic evolution of the Round Top laccolith, Trans-Pecos, Texas: Minerals, Special Issue: Mineral Deposits of Critical Elements, v. 8, no. 10, 25 p., http://doi.org/10.3390/min8100423.

University of Regina [Canada]

Guoxiang Chi and Kathryn Bethune have published 5 articles relating to the geology of the Athabasca Basin unconformity deposits:

Li, Z., Chi, G., Bethune, K.M., Eldursi, K., Quirt, D. and Ledru, P. Gudmundson, G. 2018. Numerical simulation of strain localization and its relationship to formation of the Sue unconformity-related uranium deposits, eastern Athabasca Basin, Canada. Ore Geology Reviews 101: 17–3.

Chi, G., Li, Z., Chu, H., Bethune, K.M., Quirt, D. H., Ledru, P., Normand, C., Card, C., Bosman, S., Davis, W. J., Potter, E.G. 2018. A shallow-burial mineralization model for the Unconformity-related uranium deposits of the Athabasca Basin. Scientific Communication. Economic Geology, 113(5): 1209–1217.

Wang, K., Chi, G., Bethune, K.M., Li, Z., Blamey, N., Card, C., Potter, E.G., Liu, Y. 2018. Fluid P-T-X characteristics and evidence for boiling in the formation of the Phoenix uranium deposit (Athabasca Basin, Canada): Implications for unconformity-related uranium mineralization mechanisms Ore Geology Reviews, 101: 122–142.

Chi, G., Blamey, N.J.F., Rabiei, M., Normand, N. 2018. Hydrothermal REE (xenotime) mineralization at Maw Zone, Athabasca Basin, Canada, and its relationship with unconformity-related uranium deposits – A reply. Economic Geology, v. 113, p. 998-999.

Li, Z., Chi, G., Bethune, K.M., Eldursi, K., Thomas, D., Quirt, D., Ledru, P. 2018. Synchronous egress and ingress fluid flow related to compressional reactivation of basement faults: the Phoenix and Gryphon uranium deposits, southeastern Athabasca Basin, Saskatchewan, Canada. Mineralium Deposita, v. 53, p. 277-292.

University of Regina [Canada]

Guoxiang Chi is also a coauthor of a very interesting paper on an uranium-enriched paleo-karstic bauxite deposit in China:

Long, Y., Chi, G., Liu, J., Zhang, D., Song, H. 2018. Uranium enrichment in a paleo-karstic bauxite deposit, Yunfeng, SW China: mineralogy, geochemistry, transport – deposition mechanisms and significance for uranium exploration. Journal of Geochemical Exploration, v. 190, p. 424-435.

The enrichment of uranium in a bauxite has recently been reviewed, but this is difficult to resolve due to the mobility of uranium in oxidizing environments and in considering bauxite forms by intensive weathering on the earth surface. Long, et. al. (2017) studied the samples from the deposit using an electron probe micro-analyzer and whole rock chemical analysis including rare earth elements (more).

Long, et al. found that uraninite is associated with pyrite in matrix of diaspore and kaolinite. The source of the uranium is thought to be a black rich uranium shale. Clasts of this shale where transported and deposited in in karstic depressions. In-situ weathering of the black shale mobilized the uranium which was absorbed and fixed in local reducing environments below the water table. During early diagenesis, there was further fixation of uranium and formation of uranium oxide nanocrystals (see Figure 11). During burial diagenesis, microscale uraninite formed, often near euhedral pyrite. The schematic model from the Long, et al. paper (more):

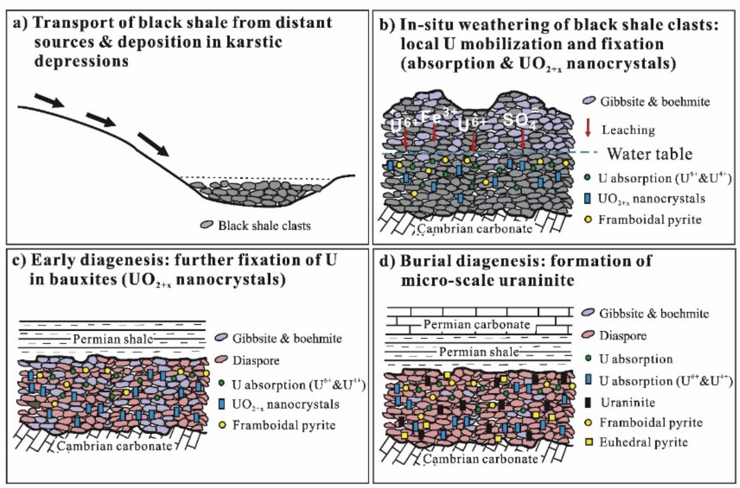


Figure 11
(Long et. al. 2017)

URANIUM & RARE EARTH GOVERNMENT RESEARCH

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

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.

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. https://pubs.er.usgs.gov/publication/70179186.

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) will soon publish 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* (*in press*).

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:

https://www.wsgs.wyo.gov/

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.

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 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. 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 12):

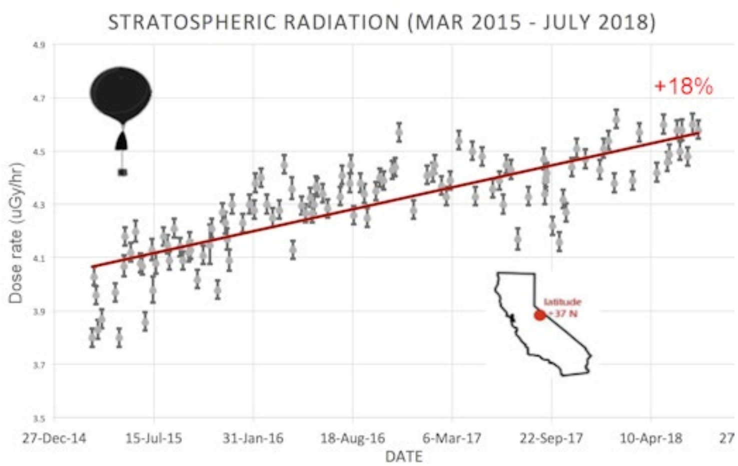


Figure 12
(Spaceweather)

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 13) 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).

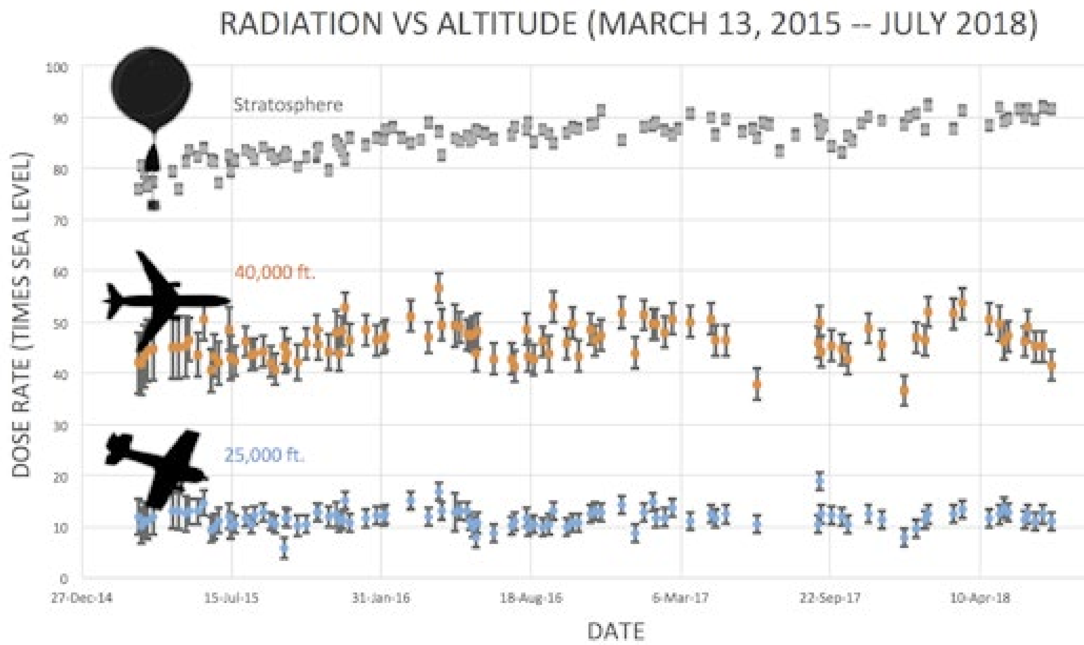


Figure 13
(Spaceweather)

For a dynamic viewing of the northern lights (*Aurora Borealis* aka Earth's magnetic field in action)), see Figure 14, 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 14
Coronal Mass Ejection (CME) Heading for Earth and the Earth's Defense

Also, red lightning has only recently been observed in detail above distant thunderheads as momentary flashes, and Smith (2019) caught a group over two big storms in Kansas this year (see Figure 15). 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 15
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 16 viewing sprites.

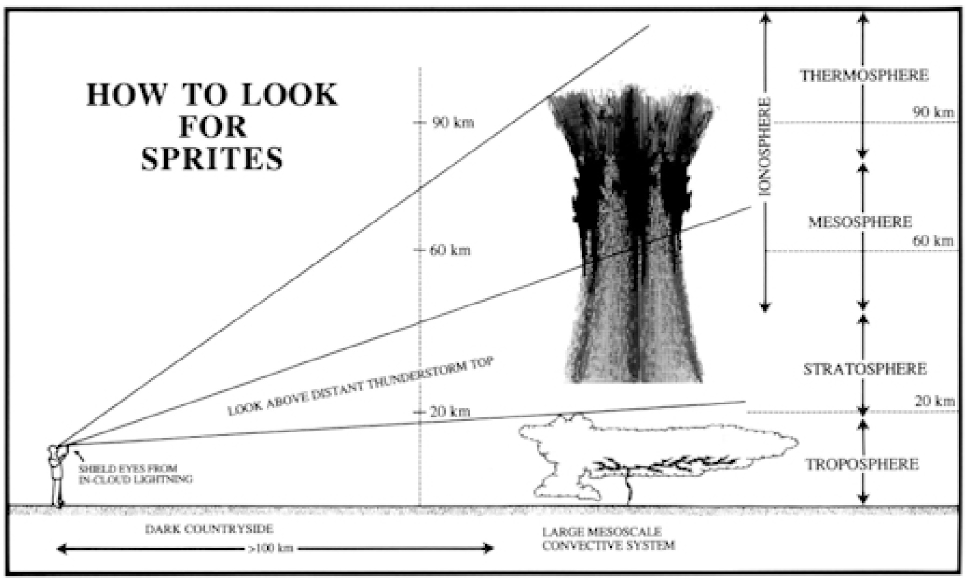


Figure 16
(Smith, 2019)

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

Recent medical reports on astronauts returning from long stays in zero gravity on the ISS show that serious damage occurs to brains (more) and issues (more). This will require rotation 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. will require additional on-site 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).

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