EMD Uranium (Nuclear Minerals) Committee

2016 EMD Uranium (Nuclear Minerals and REE) Committee Annual Report

June 18, 2016

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- **Henry M. Wise, P.G., C.P.G., (Vice-Chair: Industry),** SWS Environmental Services, La Porte, TX (Founding Member of EMD in 1977)
- **Steven S. Sibray, P.G., C.P.G., (Vice-Chair: University),** University of Nebraska, Lincoln, NE
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Advisory Group:

- **Kevin T. Biddle, Ph.D.,** V.P., ExxonMobil Exploration (retired), Houston, TX (Founding Member of EMD in 1977)
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- **Michael A. Jacobs, P.G.,** Pioneer Natural Resources, (Founding Member of EMD in 1977), ex-Tenneco Uranium Inc., Midland, TX
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- **Samuel B. Romberger, Ph.D.,** Sr. Geological Consultant, Golden, CO
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Special Consultants to the Uranium (Nuclear and Rare Earths) Committee:

- **Ruffin I. Rackley**, Senior Geological Consultant, Anacortes, WA, ex-Teton Exploration, Casper, WY (Founding Member of EMD in 1977, Secretary-Treasurer: 1977-1979, and Past President: 1982-1983)
- **Bruce Rubin**, Senior Geological Consultant, Millers Mills, NY (Founding Member of EMD in 1977) , ex-Teton Exploration
- **M. David Campbell, P.G.**, Senior Geologist, I2M Associates, LLC, Houston, TX
- **Robert A. Arrington**, VP, Exploration, Texas Eastern Nuclear, Inc (retired), College Station, TX (Founding Member of EMD in 1977)
- **Richard C. Bost, P.E., P.G.**, President, I2M Associates, LLC, Houston, TX
- **Jay H. Lehr, Ph. D.,** Science Director, Heartland Institute, Chicago (on Nuclear Power)

COMMITTEE ACTIVITIES

The AAPG Energy Minerals Division's Uranium (Nuclear and Rare Earths) Committee (UCOM) continues to monitor the activities within the nuclear power industry because it drives uranium exploration and development in the United States and overseas. Construction of new power plants and continued operation of the 99 existing nuclear power plants in the U.S., and 440 plants around the world, require large supplies of nuclear fuel (more). The uranium price is related to these demands and must be anticipated years ahead of actual sales, which in turn increases or decreases exploration as well as mining activities.

Input for this Annual Report has also 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 by Robert Gregory, P.G., Vice Chair (Government) on governmental (State and Federal) activities in uranium, thorium, and rare-earth research, with special input from other members of the Advisory Group.

Two new members have been added to the UCOM Advisory Group this past year. They are Kevin T. Biddle, Ph.D., ex-ExxonMobil Exploration VP (retired), and Michael A. Jacobs, P.G., Pioneer Natural Resources USA, Inc., Midland, Texas, and ex-Tenneco Uranium Inc.'s West Cole Uranium Mine in Texas, both of whom are founding members of the EMD in 1977.

As "nuclear minerals," thorium and rare-earth elements (REE) activities have also been monitored during the period for this Annual Report, a function approved by the UCOM in 2011. On the basis that nuclear (thorium) and REE minerals often occur in deposits together with uranium, we provide summary information on current thorium and rare-earth exploration and mining, and associated geopolitical activities.

UCOM is also pleased to remind the reader as a regular feature of the UCOM reports that the Jay M. 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. Those 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, 2015).

We are pleased to announce that Justin Drummond of Queens University, Kingston, Ontario, Canada was awarded the McMurray Memorial Grant in 2015 and 2016. Jason Nolan received the Grant in 2014 (more). Other recipients of the Grant since 2009 are presented in the following Table 1.

Table 1

Recipients of the Jay M. McMurray Memorial Grant from AAPG

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, SEVIER FORELAND 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

PUBLICATIONS AND NUCLEAR OUTREACH

The EMD co-sponsored Journal: *Natural Resources Research* has published the bi-annual *Unconventional Energy Resources: 2015 Review* in Volume 24, Issue 4, December, 2015 (more). The UCOM 2015 contribution begins on page 450 and is titled: *Energy Competition in the Uranium, Thorium, and Rare Earth Industries in the U.S. and the World: 2015*. Earlier versions include: the 2013 version (here); 2011 (here); 2009 (here); and 2007 (here).

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 Associates, LLC, contributed the final Chapter 9, 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 subjects. To review the chronological list of Dr. Conca's contributions to date, see (here).

Last year, we modified the format of the UCOM report to provide greater coverage and timely information in a more concise format. To accomplish this, within the UCOM we examine certain topics as we have in the past, such as the driving forces behind the current uranium industry conditions and activities, e.g., nuclear power plant construction, yellowcake prices, data on reserves and exploration, especially new discoveries. To support this coverage, we draw on the I2M Web Portal, which provides references and reviews of technical reports and media articles with a focus on: a) uranium exploration (more); b) mining, processing, and marketing as well as on topics related to: c) uranium recovery technology; d) nuclear-power economics, reactor design, and operational aspects that drive uranium prices (more); and e) related environmental and societal issues involved in such current topics as energy resource selection and climate change (more), since all have direct or indirect impact on the costs, mining, and utilization of uranium, thorium, and rare-earth fields.

This also includes reviews of the current developments in research on thorium (more), helium-3 (more), and fusion research (more), and environmental and societal issues related to nuclear waste (more). Current research developments in the rare-earth commodities are also covered (more).

For a review of the coverage of the various sources of information on energy and associated topics, in the form of almost 4,500 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 fields covered in the I2M Web Portal (here). The references have been cited in the form of reference links and full citations and are listed in the References section at the end of this report combined with a list for additional reading on the nature and impact of radiation, perceived or real (more).

The principal objective of this report each year is to provide a summary of the important developments in uranium exploration and production of yellowcake or U_3O_8, (and the economics that drive the uranium prices in response to plant demand) to create fuel for the 99 reactors (and those planned, under construction, or unshuttered), and the storage of their waste products in the U.S. and that of the 455 and expanding number of nuclear power plants worldwide.

We also include discussions on the status of thorium and rare-earth exploration (and development) because both are often encountered in some types of uranium deposits and which impact the economics of recovering all three products.

EXECUTIVE SUMMARY

- Uranium price is currently about $28.00 / pound U_3O_8 , which is the lowest price in 10 years, but the long-term contract price has not changed since July, 2015, at $40.00 /pound U_3O_8.

- Uranium price is expected to rise starting during the 4th Quarter, 2016 to about $40.00 / pound U_3O_8.

- Total U.S. production for 2015 was 3.3 million pounds U_3O_8, 32% lower than 2014, the lowest production since 2005.

- Arizona, New Mexico, Colorado, and Alaska all have uranium deposits that are being investigated and may be mineable.

- Total U.S. uranium drilling in 2015 amounted to 13% less than in 2014.

- Uranium is produced by open-pit and underground methods (42%), 51% by in-situ mining method, and 7% recovered as byproduct.

- Wyoming uranium mines are preparing for the price rise by producing and storing yellowcake, the Powder River Basin having 12 mines in various stages of production, 7 of which are currently operating.

- South Dakota and Nebraska have a mine each that are ready for production.

- Texas has 3 in-situ mines, with others being permitted.

- Increased mergers and acquisitions have been underway over the past few years in the U.S. and elsewhere.

- Uranium One has generally divested its holdings of U.S. uranium properties, but has maintained royalties in some cases.

- U.S. production of uranium for the 1st Quarter, 2016 was up 0.4% from 4th Quarter, 2015 but down 46% from 1st Quarter, 2015, all to be expected because of low uranium prices.

- U.S. uranium was produced during the 1st Quarter, 2016 at 6 facilities, 2 more than 4th Quarter, 2015 in Utah, Wyoming, and in Colorado (start-up planning).

- By the end of 2015, other than those in production in the U.S., one mine was on standby, one in development, 6 under permitting and licensing, one under construction, and 3 in restoration.

- The 2015 U.S. production contributed only about 7% of the U.S. market requirements to fuel U.S. civilian nuclear reactors, with 93% of the required uranium supplies imported from overseas suppliers.

- New uranium discoveries have been reported in Canada, Peru, Uruguay, Paraguay, India, Iran, and Tanzania, some of which are nearing production.

- Multiple major uranium discoveries in Canada around the periphery of the Athabasca Basin consist of very high grade ore grades along a significant strike distance, but at depths of up to 700 meters (2,100 feet) bgs.

- Major resources are available in Australia with potential for additional resources in Western Australia, Northern Territory, and South Australia and Queensland, but anti-nuclear adversaries have made inroads with the general public in Australia in the past few years, but which is expected to be dispelled in the near future during national elections.

- Foreign supplies of yellowcake to the American market comes from mines in Canada and Australia (47%), from Kazakhstan, Russia, and Uzbekistan (37%), and from Bulgaria, Czech Republic, Malawi, Namibia, Niger, and South Africa (10%), with 7% coming within the U.S.

- U.S. currently has 99 nuclear reactors in operation, with up to 6 being slated for shuttering in response to market forces involving low-priced natural gas and coal, but with 5 new reactors currently under construction.

- U.S. nuclear power construction, both Model AP-1000 or upgrades and SMRs, will increase substantially above 19% if: a) electricity demand increases as a result of improving economic conditions in the U.S., b) regulations are amended to facilitate nuclear power in the U.S., c) natural gas prices rise substantially, and d) coal production and use continues to decline.

- Estimates from government and industry forecast that fossil fuels will still account for 78% of the U.S. energy used through 2040, with natural gas usage increasing at a rate of about 2% per year.

- EIA portends that nuclear power will grow by 2.3% during the period between 2012 and 2040, but allows for a possible construction expansion rate of 4 to 6% per year, which includes SMR entry into the industry.

- TVA is attempting to mix energy sources in order to achieve lower carbon emissions by adding SMRs with wind and solar systems.

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- ❖ Global energy electricity generation will grow by about 70% between 2012 and 2040.
- ❖ Approximately 440 nuclear reactors are currently in operation in the world, with 65 under construction, 173 ordered/planned, and 337 proposed.
- ❖ China, U.S., and India will remain top 3 coal-consuming countries, amounting to more than 70% of world coal use through 2014, but including SE Asia coal use.
- ❖ China revised estimates in planning for increasing nuclear power production by 60% during the period of 2012 to 2040, with 20 plants currently under construction.
- ❖ Post-2011 tsunami Japan is re-permitting most of their original nuclear power plants and all but two such plants will return to operation by 2020.
- ❖ Russia currently has 10 nuclear power plants under construction.
- ❖ Small Modular Reactors (SMRs) are under development by as many as 15 companies in the U.S. and overseas.
- ❖ Korea will experience a sizable increase in nuclear generating capacity.
- ❖ Saudi Arabia and UAE have multiple nuclear plants under construction.
- ❖ Canada and Germany may phase out nuclear power, but Sweden recently reversed their opposition.
- ❖ Energy-related CO_2 emissions are projected to increase by 34% from growth in Non-OECD (major companies) from relying heavily on fossil fuels (coal, natural gas, wood, etc.).
- ❖ Yucca Mountain nuclear waste storage facility may still be completed, but even with the retirement of the Senior Senator from Nevada, opposition exists from left-wing political intractability.
- ❖ Other waste storage sites are under review.
- ❖ Commercial renewable energy systems continue to grow in popularity in remote regions, but still receive substantial subsidies so true costs of electricity are often unknown, especially when a back-up power grid is required for overall grid stability.
- ❖ Hydropower, such as classical dams and pumped-storage power systems, is showing and increase in the energy mix in some states.
- ❖ Al least 9 countries have important thorium resources that may be available, if needed.

- ❖ Research continues on using thorium in nuclear reactors.
- ❖ Rare-earth resources are now known in 35 countries, but 42% are owned /controlled by China.
- ❖ China reduced production of REE a few years ago but in 2015, China increased production by 15% to 95,000 tons, which consists of 86% of the world's total rare earths.
- ❖ China also has a highly developed supply-chain for rare-earth productions and separation.
- ❖ China conducts a major effort in research and development regarding manufacturing involving rare-earth products, considering the effort important to its economy.
- ❖ University research in uranium continues to decrease because of the long-term slump of prices and general availability of funding. When prices rise, research funding will return to the U.S. universities, the U.S. Geological Survey, and various state geological surveys.
- ❖ Atmospheric radiation is now being monitored on a regular basis by students using large weather balloons and the reported levels are surprising.

INTRODUCTION

The emphasis of this EMD Annual Report will continue to cover recent and forecasted uranium (yellowcake) prices and how the uranium industry is responding to the current economic conditions in exploration and mine development, and to the expectations for the future. Thorium also is an important component to many rare-earth/uranium deposits and although thorium is not currently used as fuel to produce electricity, it is being considered as a fuel component by numerous companies in the U.S. and overseas. In some cases, rare-earth deposits also contain uranium in recoverable amounts and so the rare-earth prices are also important considerations in developing some deposits into viable, economic ventures.

The uranium market is guided to a large extent by expectations displaced years ahead by today's nuclear power-plant operations, anticipated construction, and plant shuttering and retirement plans. As discussed previously (EMD UCOM 2015 Annual Report (more) and EMD UCOM 2015 Mid-Year Report (more)), energy competition between nuclear and coal, natural gas, as well as with renewable energy projects are based on the cost to produce electricity and on the impact on the environment, complicated by the federal government's subsidizing and promoting wind and solar energy projects, all within a complex, transitional energy framework in the U.S. today (more).

To this framework, the concept of "informed consent of the public," fostered by the federal government years ago pandering to special interests, has become polarized in energy selection by political influences that trump rational selection based on economic and environmental factors in the U.S. and other countries. This results in unnecessary delays in the permitting process under the guise of opposing reviews introduced during public interaction, but ignoring informed scientific information and harboring NIMBY or generalized anti-nuclear intentions (see Figure 1).

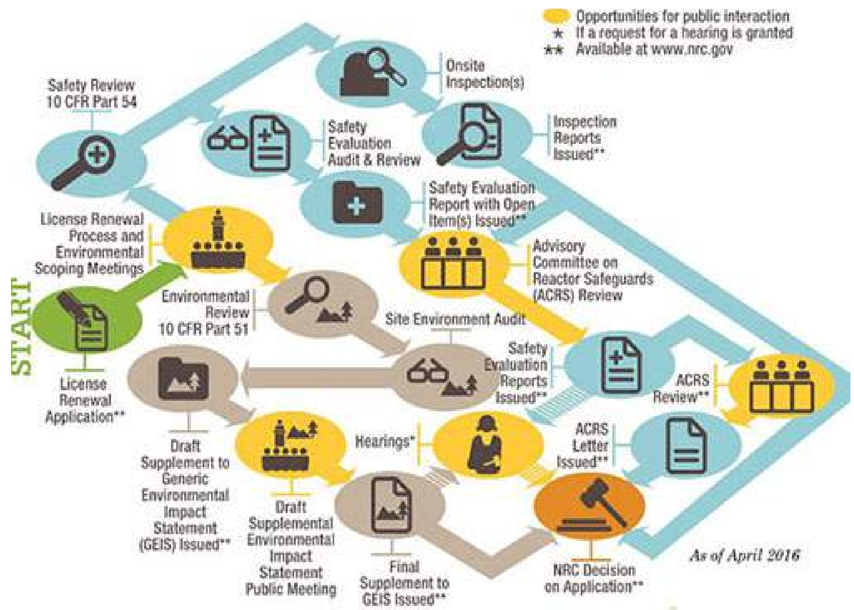


Figure 1 – Nuclear Power Plant License Renewal Process

(NRC (2016))

Nuclear energy has been vetted over more than 5 decades, especially after each environmental incident, and 99 nuclear plants, with more under construction, must be re-fueled every three to five years. Uranium company exploration activities are influenced by uranium prices, and especially in developing mining operations. Low-cost operations such as in-situ mining or high-grade mining of underground or shallow open-pit operations can produce yellowcake while prices are low but higher cost operations cannot operate at a profit.

At present, about 42% of uranium comes from conventional mines (open pit and underground) about 51% from in situ leach, and 7% is recovered as a by-product from other mineral extraction. In total this mined uranium accounts for 84% of annual nuclear power station requirements (more). Either short-term spot prices or long-term contracted prices control supply according to the anticipated demand coming from utilities or owners of nuclear power plants.

Uranium Prices

Farther down the supply line, uranium prices depend on the yellowcake that is available for processing into fuel pellets for loading into nuclear power plants. As new power plants are announced, the uranium market becomes aware of this potential requirement but the actual need will not be realized for months, if not for a few years. Plant management must estimate when loading will be necessary at some point in the foreseeable future.

Each plant requires about 50,000 pounds of equivalent yellowcake in the form of refined pellets every few years. The fuel assembly lowered into water creates fission that heats the water, which is modulated by graphite control rods in most current reactors that operate 24 hours a day 7 days a week. The system is designed for continuous production on average of 500 MW of electricity, usually for 3 to 5 years until time for refueling with new assemblies of fuel pellets.

The used-fuel assemblies are then stored on-site for cooling in pools of water, well circulated to maintain temperature control. This system was the problem in the Fukushima incident. The circulation system was interrupted allowing the water to boil off exposing the control rods which then oxidized producing radioactive steam that had direct access to the atmosphere. The excess hydrogen created by the boiling water, collecting in the building, then ignited, blowing the roof off the building in a dramatic fashion (more). The incident was called a "mega-disaster" by the media, but this was refuted later by many unbiased reporters (more).

After some time, the spent fuel would be sufficiently cooled for shipment to the national storage facility at Yucca Mountain. The federal storage facility designed to store spent fuel at Yucca Mountain in Nevada has yet to be opened, primarily as a result of political rather than technical issues (more). However, a low-level radioactive storage site, such as the WIPP facility in New Mexico has been in operation for some years (more).

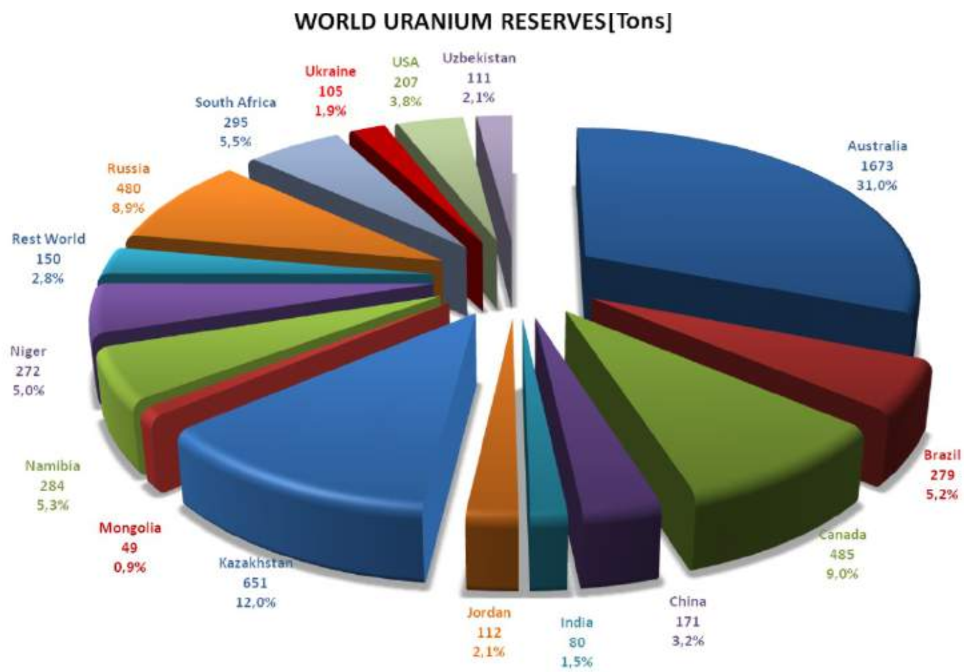
With more than 400 nuclear power plants in current operation worldwide, they require some 20 million pounds of yellowcake to be available for processing to fuel pellets to meet the various 3-5 year cycles of the plants. As each new plant construction is announced, an additional 50,000 pounds would be 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.

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. 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 and other types of deposits elsewhere in the world (Peru, Uruguay and Paraguay, India, Iran, and Tanzania) so there will be no shortage of producing mines over the next few decades (more).

But this may even create market conditions that will keep the price below $75.00 per pound ($U_3O_8$). All told 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 base on a worldwide consumption rate of 50 million pounds U_3O_8/year over a 3-year fuel cycle for 450 reactors (more). Further distribution of potentially economic uranium deposits occur in many parts of the world (see Figure 2). Based on recent discoveries in Canada, its percent of acknowledged world reserves will rise considerably as will that of others countries.

Figure 2

(After IAEA)



One condition that could develop is a long-term over supply of uranium from a plethora of high- and low-grade deposits that would keep prices below $50.00/ pound. The second condition created by the production of very high grade, large reserves of uranium that are likely present around the periphery of the Athabasca Basin of Canada (where new discoveries have been made in the past few years) could be produced at prices lower than most other uranium mining projects. Some grades are so high that the beginning of robotics mining may well be in the offing. This may raise the cost to mine and transport in the beginning but 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 Chinese (more) and 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?

Electrical Generation by Nuclear Power

Global nuclear electricity generation is expected to almost double by 2040, according to the latest projection by the U.S. Department of Energy's Energy Information Administration (EIA). Most of this growth will be in the developing world, it said. Total world energy consumption will increase by almost 50%, from 549 quadrillion British thermal units in 2012 to 815 quadrillion Btu in 2040. This growth will be driven by industrialization in non-OECD countries, especially in Asia, the EIA said. The Organization for Economic Cooperation and Development (OECD) is a unique forum where the governments of 34 democracies with market economies work with each other, as well as with more than 70 non-member economies to promote economic growth, prosperity, and sustainable development.

World Nuclear News (WNN) reports that although consumption of non-fossil fuels is expected to grow faster than consumption of fossil fuels, fossil fuels will still account for an incredible 78% of primary energy in use in 2040. Coal will be the world's slowest growing energy source, rising by 0.6% annually from 153 quadrillion Btu in 2012 to 180 quadrillion Btu in 2040.

But China, the U.S., and India will remain as the top three coal-consuming countries, together accounting for more than 70% of world coal use. Natural gas consumption will grow 1.9% annually over the same period. According to the EIA, global electricity generation will likely increase by 69% between 2012 and 2040, from 21.6 trillion kWh in 2012 to 25.8 trillion kWh in 2020 and 36.5 trillion kWh in 2040, as per WNN.

While renewable energy sources as promoted by the EIA are projected to be the world's fastest growing energy source for electricity production between 2012 and 2040, growing an average 2.9% annually from a very small base (notice that the EIA does not list the kilowatt-hours produced). Nuclear energy, on the other hand, will be the third fastest growing after natural gas. Global nuclear generating capacity is expected to see 2.3% annual growth between 2012 and 2040, from 2.3 trillion kilowatt-hours to 4.5 trillion kWh. Its share of total primary energy over this period will increase from 4% to 6%, or more if the current expansion continues worldwide and in the U.S. (WNN)

However, EIA (2016) has expressed concerns about energy security and greenhouse gas emissions support the development of new nuclear generating capacity, the EIA said. China alone, which plans to add 139 GWe of nuclear capacity by 2040, accounts for 61% of world nuclear capacity growth over the period. But in the U.S., EIA indicates that between 2013 and 2040, nuclear power's share of total generation may fall from 19% to 15% in its High Oil and Gas Resource case and to 18% in its High Oil Price case, where higher natural gas prices lead to additional growth in nuclear capacity (WNN-2015).

But should the electricity demand increase as a result of improving economic conditions in the U.S., and regulations are amended to favor nuclear power in the market place, combined with increasing natural gas prices (as predicted) and continued decline in coal use (as needed for the climate), then nuclear power could expand well beyond its current 19% of total energy generation in the U.S.

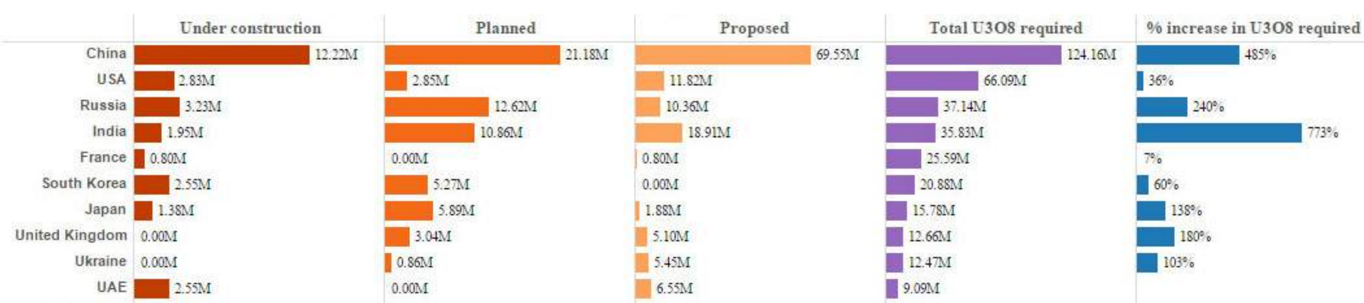
Among OECD countries, South Korea will have a sizeable increase in nuclear generating capacity (15 GWe), the EIA notes. At the same time, reactor shutdowns in Canada and Europe, together with reduced capacity in Japan, may see an overall drop of 6 GWe in nuclear capacity in OECD nations by 2040, but this is not likely to occur. All of these groups are showing renewed interest in maintaining or increasing their nuclear generating capacity if only on economic grounds while not considering climate needs.

Despite the move towards lower-carbon energy sources, energy-related CO_2 emissions are projected to increase from 32 billion tonnes in 2012 to 36 billion tonnes in 2020 and then to 43 billion tonnes in 2040, a 34% increase from 2012 to 2040. Much of the growth in emissions is attributed to developing non-OECD nations, many of which continue to rely heavily on fossil fuels to meet the fast-paced growth of energy demand, as per EIA.

To meet the anticipated increase in demand for electricity, the U.S. now has 5 new reactors under construction and China has 20, Russia has 10 under construction, and together with others in construction elsewhere, they will create the greatest demand in the history of nuclear power for U_3O_8 production over the next decade (as indicated in Figure 3). But the other countries will be creating serious demands as well as shown in Figure 3; for the rest of the list see reference (more).

Figure 3

U_3O_8 Needs 2017 to 2025



The Impact of Japan

As Japan restarts their nuclear fleet, information is coming in on the economic damage that occurred to Japan not as a result of the devastation of the tsunamis of 2011, but as a result of the extra cost for importing natural gas and attempts to ramp up wind and solar energy on a large scale that failed has impacted Japan's economy severely. This has occurred while their nuclear plants were shuttered, but the plants have begun to be restarted, and the economic stress should be relieved over the next decade (more).

Freebairn (2015) reports that the Japanese fleet of 43 nuclear reactors, with a total installed capacity of about 42,000 MW, has been largely idled since September 2013, when the country adopted stricter nuclear safety requirements in the wake of the Fukushima tsunamis that damaged a few power plants along the coast of Japan.

Reactors have to receive a safety review approval from the Nuclear Regulation Authority, secure the go-ahead from local towns and prefectures, and obtain final NRA approval of preoperational tests before it can load nuclear fuel and begin to generate electricity once again.

Twenty-four of the 43 reactors have applied to NRA for safety review; it is unclear how many of the remaining units will apply in the future. In addition, Japan Electric Power Development Co. has applied for NRA safety review of its new Ohma nuclear reactor, which is under construction and could come online by the end of 2021.

As indicated in our 2015 Mid-Year report (more, p. 11), additional restarts of reactors in Japan will be a positive event from a market sentiment perspective, but it will have little impact on the actual supply and demand equation until additional reactors are restarted (more). Five more reactors in Japan will be restarted in 2016, and seven in 2017. Ultimately, 36 reactors are expected to be back online in Japan by 2020 with others under construction.

Current and ongoing updates on activities in Japan are available via the I2M Web Portal. The important role Japan is playing in the nuclear power expansion in the world, either directly or indirectly, is evident in the search results (more).

Future Uranium Price Increases

As indicated last year's UCOM reports, the current spot prices have been languishing since 2011, but the fundamentals indicate that a very large demand-and-supply gap will open up soon, or so the uranium soothsayers claim. The uranium industry spot uranium price has experienced its worst year to date (June, 20[1]6) in more than 10 years with uranium prices currently sitting at $27.25 / pound U_3O_8 as of May 31 (see Figure 4). This is the lowest uranium spot price since 2005. On the other hand, the long-term uranium price (long-term contracted price) has not changed since July, 2015, sitting at $44 per pound for almost a one-year period (more).

Long-Term Contract Prices

EIA (2016) recently reported that owners and operators (COOs) of U.S. civilian nuclear power reactors purchased a total of 57 million pounds U_3O_8e (equivalent*) of deliveries from U.S. suppliers and foreign suppliers during 2015, at a weighted-average price of $44.13 per pound U_3O_8. The 2015 total of 57 million pounds U_3O_8e increased 6% compared with the 2014 total of 53 million pounds U_3O_8. The 2015 weighted-average price of $44.13 per pound U_3O_8e decreased slightly by 4% compared with the 2014 weighted-average price of $46.16 per pound U_3O_8.

Figure 4 – Average U_3O_8 Spot Prices 2005 to April, 2016 (US$)
(From: http://www.uxc.com/)

Six percent of the 57 million pounds U_3O_8 delivered in 2015 was U.S.-origin uranium at a weighted-average price of $43.86 per pound. Foreign-origin uranium accounted for the remaining 94% of deliveries at a weighted-average price of $44.14 per pound. Uranium originating in Kazakhstan, Russia, and Uzbekistan accounted for 37% of the 57 million pounds. Australian-origin and Canadian-origin uranium together accounted for 47%. The remaining 10% originated from Bulgaria, Czech Republic, Malawi, Namibia, Niger, and South Africa (more).

COOs purchased uranium of three material types for 2015 deliveries from 36 sellers, two more than in 2014. Uranium concentrate was 55% of the 57 million pounds U_3O_8 delivered in 2015. Natural UF_6 was 30% and enriched UF_6 was 15%. During 2015, 21% of the uranium was purchased under spot contracts at a weighted-average price of $36.80 per pound. The remaining 79% was purchased under long-term contracts at a weighted-average price of $46.04 per pound.

Spot contracts are contracts with a one-time uranium delivery (usually) for the entire contract and the delivery is to occur within one year of contract execution (signed date). Long-term contracts are contracts with one or more uranium deliveries to occur after a year following the contract execution (signed date) and as such may reflect some agreements of short and medium terms as well as longer term.

New and Future Uranium Contracts

In 2015, COOs signed 54 new purchase contracts with deliveries in 2015 of 12 million pounds U_3O_8e at a weighted-average price of $37.97 per pound. Nine new contracts were long-term contracts with 24% of the 2015 deliveries and 45 new contracts were spot contracts with 76% of the deliveries in 2015.

COOs report minimum and maximum quantities of future deliveries under contract, to allow for the option of either decreasing or increasing quantities. As of the end of 2015, the maximum uranium deliveries for 2016 through 2025 under existing purchase contracts for COOs totaled 183 million pounds U_3O_8. Also as of the end of 2015, unfilled uranium market requirements for 2016 through 2025 totaled 259 million pounds U_3O_8. These contracted deliveries and unfilled market requirements combined represent the maximum anticipated market requirements of 442 million pounds U_3O_8e over the ten-year period for COOs.

Uranium Feed, Enrichment Services, Uranium Loaded

In 2015, COOs delivered 41 million pounds U_3O_8 of natural uranium feed to U.S. and foreign enrichers. Forty three percent of the feed was delivered to U.S. enrichment suppliers and the remaining 57% was delivered to overseas enrichment suppliers (EIA, 2016).

Since the beginning of 2016, Haywood (2016) reports that there has been a significant difference in how uranium stocks have reacted to the price movements so far this year. Their report states that the TSX Venture Exchange has made gains of 29% to date. Haywood indicates that exploration and development companies will benefit from strong long-term fundamentals in the uranium industry, underpinned by a deep global reactor construction increase of more than 60 reactors that will require fuel over the next decade.

Many of the companies are counting on future price increases within the next year or two; hence the funding they are receiving is to be used to move their projects forward in anticipation of production within the next few years.

The Focus Economics (2016) report states that prices have been under pressure since the nuclear incident (no deaths) in Fukushima in 2011, but which led to a sharp decrease in demand for the metal and the closure of numerous nuclear reactors around the world. Moreover, the uranium market remains oversupplied due to excess U_3O_8 inventories, thus putting downward pressure on prices. However, a depletion of stockpiles coupled with the construction of new reactors, particularly in countries such as China, India, Russia, as well as others in the Middle East, Argentina, etc., will boost prices going forward.

The Focus analysts surveyed expect the uranium spot price to rise by the 4^{th} Quarter, 2016 to an average of about $40.00 per pound U_3O_8, picking up in 2017 to an average of around $45.00 a pound. Haywood (2016) also anticipates gains for uranium in 2016, with up to 12 reactors under construction and due to be commissioned this year, with 18 more reactors will be in operation in 2017, which will increase demand for uranium, and with a more predictable and normalized supply/demand response for the uranium industry emerging in the coming years.

While still somewhat bleak over the past few months, based on the uranium industry analysts, the outlook on the future of the uranium industry is positive. Haywood analysts expect the period from 2017-2025 to be a landmark period for the nuclear industry and uranium stocks as the global operating nuclear reactor fleet expands (more). In the meantime, low prices have prevailed and some large uranium mining companies have cut production in a few mines (e.g., in Canada (more)), while some have announced increased production (in Canada (more); in Kazakhstan (more)).

In the U.S., Wyoming operations appear to be preparing for the price increase. The Powder River Basin has 12 projects underway, 7 of which are currently active in situ mining operations (see Figure 5). Peninsula Energy has just delivered its first shipment of yellowcake per an existing utility contract (more), while other companies are likely stockpiling yellowcake waiting for improved prices (more).

For activities in South Dakota (see (more)), and for those in Nebraska, see (more). Texas contains a number of uranium deposits located from Goliad County in the northeast held by Uranium Energy Corp. (more) to the Alta Mesa Mine operated by Mestena Uranium, Inc. in the Brooks County, Texas to the south. Energy Fuels has recently acquired Mestena (more). Other deposits have been produced for years while others are under development (more). Uranium Energy Corp. also operates projects in New Mexico, Arizona, Colorado, and Wyoming (more). In addition, UEC also has two projects in Paraguay (more) and extensive experience in in-situ mining (more).

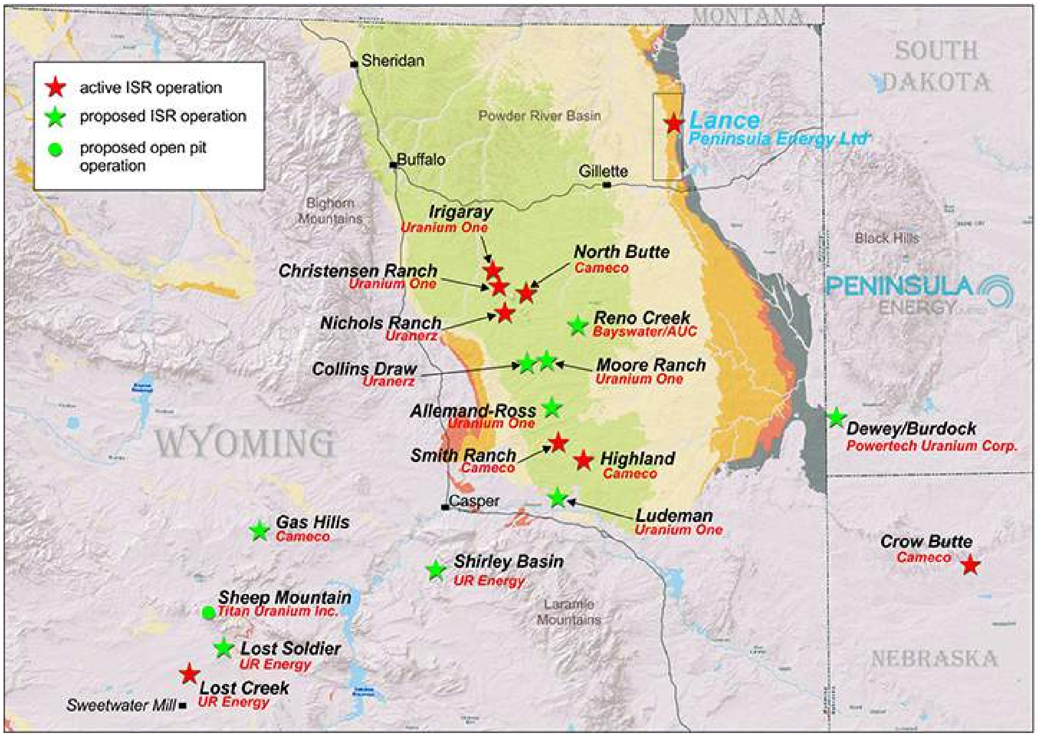


Figure 5 – Wyoming (plus South Dakota and Nebraska) Uranium Exploration and Mining Areas (From Peninsula Energy)

For Texas, the U.S. Geological Survey (2015) guesstimates that around 220 million pounds of undiscovered, recoverable U_3O_8 could occur within three trends in the Texas Coastal Plain. This represents nearly twice the pounds of uranium that has already been identified and/or produced from mines in the Texas region (Figure 6).

Earlier, Campbell and Biddle (1977) summarized NURE results for exploration in the onshore Tertiary formations of the U.S. Gulf Coast area emphasizing a) the importance of groundwater hydrochemistry, b) flow-path analysis, c) presence of salt domes, d) the presence of methane and/or H_2S, e) the likely trends of particular interest, and f) the methods of bracket drilling for locating the geological / hydrochemical interface of oxidized and reduced sediments along which uranium mineralization may occur (see Figure 7).

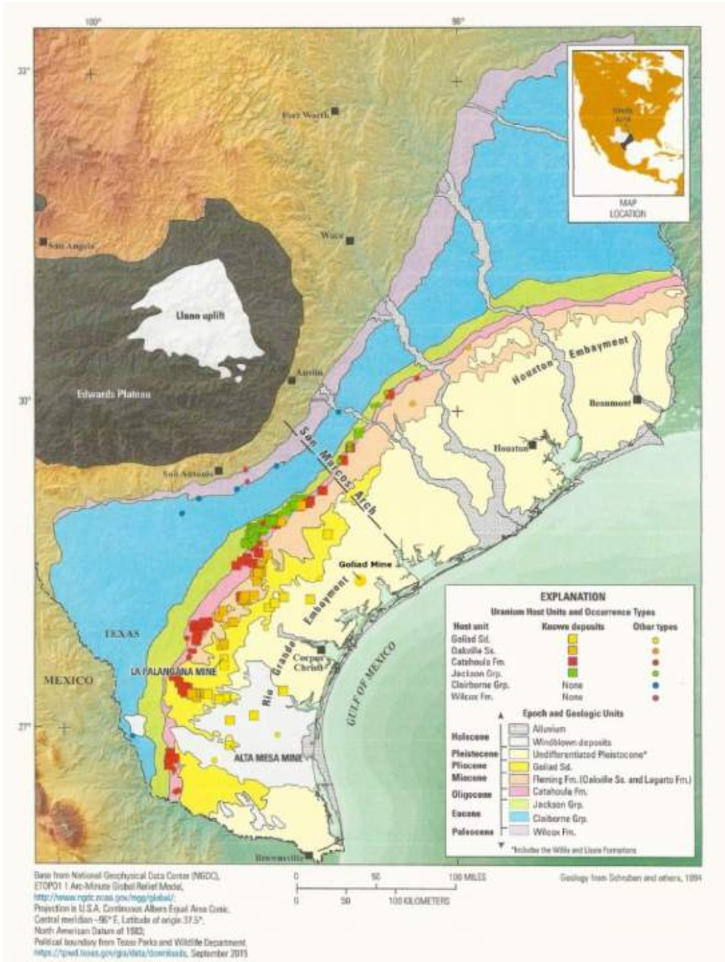
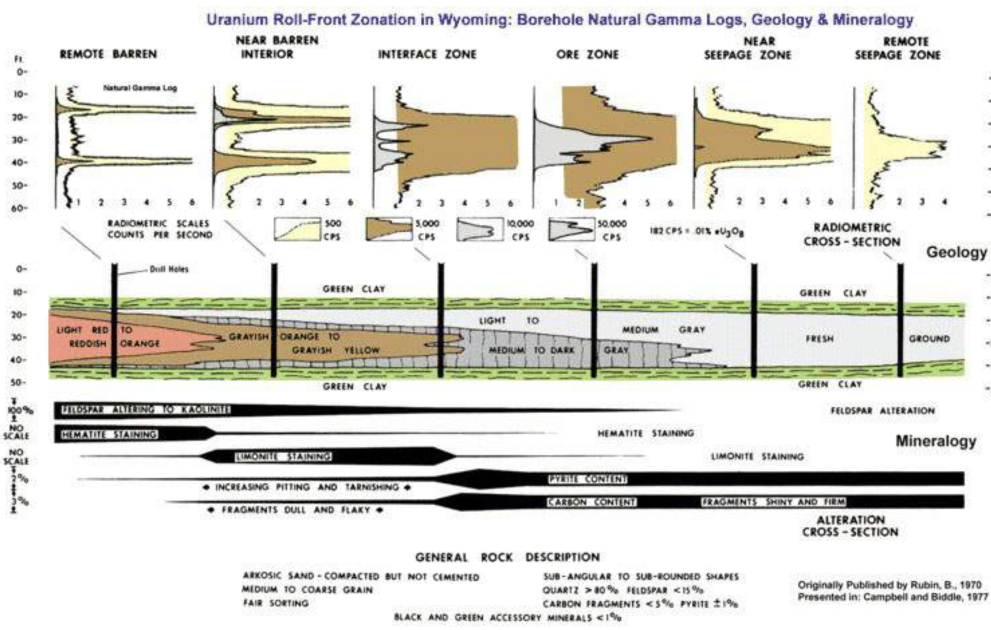


Figure 6 – Texas Uranium Exploration and Mining Areas (USGS)
(Click to Enlarge)

Figure 7



The Rio Grande Embayment region appears to contain the largest estimated undiscovered resource, with a calculated mean total of 200 million pounds of undiscovered U_3O_8, whereas the Houston Embayment sub-tract region is estimated to host about 20 million pounds of U_3O_8, but based on leads recognized by Campbell, *et al*., (2015, pp.22-25), that there are probably many more undiscovered uranium deposits of possible economic value to be found in Tertiary sandstone-hosted roll-front deposits in east and northeast Texas. They would be located down the hydraulic gradient from the Catahoula Tuff and two Tertiary lignite belts that occur across Texas and up into Northeast Texas in the Jackson and Wilcox formations, all of which contain uranium and serve as potential source sediments.

As indicated, the Texas lignite contains leachable uranium contained within the lignite (see Warwick, *et al*., 2012), 2012). The Catahoula Tuff, which consists of volcanic ash that also contains leachable uranium, was previously considered to be the sole source of uranium that found it its way in migrating groundwater to participate in the classic uranium roll fronts of uranium ore similar to those known in south Texas and Wyoming, and elsewhere in the world.

Among the three main trends (see Table 2), the Catahoula-Oakville trend, as a whole, has the largest estimated undiscovered resource (calculated mean total of 88 million pounds U_3O_8), followed by the Goliad tract (73 million pounds of U_3O_8) and the Claiborne-Jackson tract (59 million pounds of U_3O_8).

Trend name	Depositional setting	Geologic units	Age	Trend	Protospective (km²)	N_{known}	N_{und}	Probability of at least the indicated amount of undiscovered U_3O_8 (lbs)			Mean undiscovered U_3O_8 resources (lbs)	Identified U_3O_8 resources (lbs)
								0.9	0.5	0.1		
Claiborne-Jackson	Marine-coastal; barrier island/ strand plain system	Claibome Group Jackson Group	Eocene	RE	38,460	18	27	13,000,000	48,000,000	99,000,000	53,000,000	25,753,429
				HE	62,670	1	3	370,000	4,600,000	14,000,000	6,400,000	675,000
Catahoula-Oakville	Transitional; fluvial-coastal; channels and deltaic	Catahoula Formation Oakville Sandstone	Oligocene to Miocene	RE	14,220	35	41	29,000,000	79,000,000	130,000,000	82,000,000	68,815,764
				HE	16,710	0	3	350,000	4,900,000	14,000,000	6,400,000	450,000
Goliad-Willis-Lissie *	Fluvial; meander belts, flood plains	Goliad Sand, Willis and Lissie Formations	Pliocene to Pleistocene	RE	45,200	10	33	20,000,000	53,000,000	130,000,000	66,000,000	44,906,694
				HE	52,250	0	4	370,000	5,300,000	16,000,000	7,000,000	0
* Same Trend in Houston Embayment Area				Total	229,510	64	111				220,000,000	140,600,887

Table 2 – Possible Undiscovered Uranium Resources in Texas
(Source: USGS (Mihalasky (2015)**))**

The Texas uranium trends also likely extend into Mexico, but because of the civil disorder present in that part of Mexico, exploration companies are hesitant to invest in exploration under such conditions. The trend may also extend into central and northern Louisiana, Mississippi, and Alabama, in areas also occurring down dip from the lignite zones.

The NURE groundwater data are useful in exploration (more). Combined with the presence of salt domes (and associated surrounding fault systems and the availability of methane (and/or H_2S) migrating up the faults from below and around salt domes), these "frontier" areas will likely produce additional uranium resources of possible economic interest to depths of 1,500 feet or more.

In New Mexico, enCore Energy Corp has entered into a joint venture for tolling with Energy Fuels (which is merging with Uranerz) and is becoming the largest integrated uranium production company focused solely on the U.S. and has a 100% interest, with no holding costs, on 115,000 acres (46,400 ha) of private mineral rights in New Mexico, including the Crownpoint and Hosta Butte uranium deposits. These deposits, recently obtained from Uranium Resources International (URI), which is currently occupied focusing on a uranium deposit in Turkey, contain an indicated resource of 26.6 MM pounds U_3O_8 at an average grade of 0.105% e U_3O_8 and an inferred resource of 6.1 MM pounds U_3O_8 at an average grade of 0.110 e U_3O_8.

It should be noted that the grade of resources has been classified by logging, apparently not by actual laboratory results from core samples, unless the logging measured ^{235}U. Also, a portion of these resources are under NRC license. The Company also holds certain processing rights at the White Mesa Uranium Mill of Energy Fuels in Blanding, Utah (more).

In Colorado, Western Uranium the Sunday Mine Complex property consists of approximately 233 contiguous unpatented mining claims that covers about 3,748 acres (1,517 ha) located within the southern third of the prolific Uravan Mineral Belt within Big Gypsum Valley. The underground mine has been in operation for many years since the mid 1950's, and most recently between 2007 - 2009. Historic production is estimated to be between about 1,870,000 pounds to 5,000,000 pounds of uranium. Complete production records are not available.

Western Uranium was formed by the merger between Homeland Uranium Inc. and Pinon Ridge Mining LLC following the acquisition of Pinon Ridge Mining LLC. The group also controls five other projects in Colorado and southeastern Utah (more).

Canadian-based Powertech (USA), now called Azarga Uranium Inc., is currently evaluating roll-front uranium deposits in its Centennial Project in Weld County on Colorado's eastern plains. In response to the proposed mining in Weld county, state lawmakers have put forward two proposals to more closely regulate uranium mining in Colorado; the first would require that mining companies prove that groundwater would not be adversely affected before mining could begin; the second would assure that local governments have the power to set health and environmental standards (more).

Azarga also holds the Aladdin Deposit in Wyoming along with the largest known uranium deposit in Kyrgyzstan. Additional investment holdings include Uranium Resources, Inc. and Western Uranium Corporation. Technical reports for all four deposits are available (more).

The U.S. uranium companies currently conducting detailed drilling on their holdings are preparing for production within the next few years on the basis that they expecting uranium prices to rise significantly soon. Similar activities are under way in Canada, South America, India, Tanzania, Russia, but not in Australia at the present time. As Japan, China, Russia, and other countries, including the U.S., continue to initiate new nuclear plant construction, demand will out of necessity foster the long-awaited rise in the price of uranium.

URANIUM PRODUCTION IN THE U.S.

1st Quarter 2016

U.S. EIA (2016) reports that U.S. production of uranium concentrate in the first quarter 2016 was 626,522 pounds U_3O_8, up 0.4% from the 4th Quarter 2015 and down 46% from the 1st Quarter 2015. During the 1st Quarter 2016, U.S. uranium was produced at six U.S. uranium facilities, two more than in the 4th Quarter 2015. For definition of terms, see Glossary (here).

U.S. uranium mill in production (state):

1. White Mesa Mill (Utah): Energy Fuels Sale
   Operating-processing alternate feed (Capacity of 2,000 st of ore per day)

2. Shootaring Canyon Uranium Mill (Utah) - On Standby - Capacity of 3,750 st/d)
3. Sweetwater Uranium Project (Wyoming) - On Standby - Capacity of 3,750 st/d)
4. Pinon Ridge Mill (Colorado) - Planning Stage

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

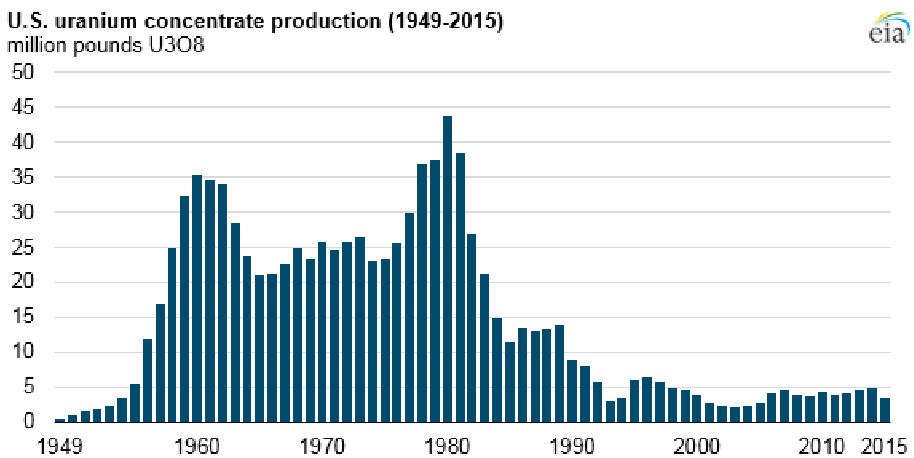
1. Crow Butte Operation (Nebraska): Cameco
2. Hobson ISR Plant / La Palangana (Texas): Energy Fuels
3. Lost Creek Project (Wyoming): UR Energy
4. Nichols Ranch ISR Project (Wyoming): Energy Fuels
5. Smith Ranch-Highland Operation (Wyoming): Cameco
6. Willow Creek Project (Wyoming): Uranium One
7. Ross Energy Central Processing Plant (Wyoming) First Quarter Production
8. Alta Mesa Project / Mestena Uranium (Texas): Energy Fuels

Final 2015 Total Production

U.S. uranium concentrate production totaled 3,343,207 pounds U_3O_8 in 2015. Because of the continuing decline in yellowcake prices, this amount was 32% lower than the 4,891,332 pounds produced in 2014 and the lowest annual U.S. production since 2005. U.S. production in 2015 represents 7% of the 2015 anticipated uranium market requirements of 46.5 million pounds for U.S. civilian nuclear power reactors, contrary to EIA projections, these requirements are expected to rise as U.S. utilities turn to U.S. and Canadian producers to meet their requirements.

Historically, uranium production in the U.S. has experienced two major periods of growth, one during the late 1950s to fuel the "cold war", the second to fuel nuclear power plant expansion, until the Three-Mile Island incident unleased a media frenzy of fear mongering among the U.S. public while the Chernobyl disaster in the Soviet Union a few years later that curtailed U.S. nuclear power plant construction (see impact on uranium mining in Figure 8). Many of the current 99 power plants operating in the U.S. were built during the last expansion.

Figure 8



For additional notes on potential production, see the Notes at the bottom of Table 3. The plant sites listed in Table 3 are capable of producing a total of about 24 million pounds of U_3O_8 per year, and a number of other projects in the U.S. will be entering operation within the next 5 years, assuming the anticipated price rise actually occurs. U.S. utilities should be required to buy American produced uranium first.

URANIUM EXPLORATION IN THE U.S.

Total uranium drilling in 2015 was 1,518 holes covering 0.9 million feet, amounting to13% fewer holes than in 2014, as would be expected with decreasing uranium prices (see Figure 9). Drilling will increase substantially as the predicted "dramatic" price increases finally occur. If the number of mergers and acquisitions currently underway within the uranium industry is any indication, the industry is preparing to expand production within the next few months or early next year (more).

Table 3
(EIA, 2016)

U.S. URANIUM IN-SITU-RECOVERY PLANTS BY OWNER, LOCATION, CAPACITY, AND OPERATING STATUS

In-situ-leach plant owner	In-situ-leach plant name	County, state (existing and *planned* locations)	Production capacity (pounds U_3O_8 per year)	Operating status at end of			
				2014	1st quarter 2015	2nd quarter 2015	3rd quarter 2015
AUC LLC	Reno Creek	*Campbell, Wyoming*	2,000,000	Developing	Developing	Developing	Partially Permitted And Licensed
Azarga Uranium Corp.	Dewey Burdock Project	*Fall River and Custer, South Dakota*	1,000,000	Partially Permitted And Licensed	Partially Permitted And Licensed	Partially Permitted And Licensed	Partially Permitted And Licensed
Cameco	Crow Butte Operation	Dawes, Nebraska	1,000,000	Operating	Operating	Operating	Operating
Hydro Resources, Inc.	Church Rock	*McKinley, New Mexico*	1,000,000	Partially Permitted And Licensed	Partially Permitted And Licensed	Partially Permitted And Licensed	Partially Permitted And Licensed
Hydro Resources, Inc.	Crownpoint	*McKinley, New Mexico*	1,000,000	Partially Permitted And Licensed	Partially Permitted And Licensed	Partially Permitted And Licensed	Partially Permitted And Licensed
Lost Creek ISR LLC	Lost Creek Project	Sweetwater, Wyoming	2,000,000	Operating	Operating	Operating	Operating
Mestena Uranium LLC	Alta Mesa Project	Brooks, Texas	1,500,000	Producing	Producing	Standby	Standby
Power Resources, Inc. dba Cameco Resources	Smith Ranch-Highland Operation	Converse, Wyoming	5,500,000	Operating	Operating	Operating	Operating
South Texas Mining Venture	Hobson ISR Plant	Karnes, Texas	1,000,000	Operating	Operating	Operating	Operating
South Texas Mining Venture	La Palangana	Duval, Texas	1,000,000	Operating	Operating	Operating	Operating
Strata Energy Inc	Ross CPP	Crook, Wyoming	375,000	Under Construction	Under Construction	Under Construction	Under Construction
URI, Inc.	Kingsville Dome	Kleberg, Texas	1,000,000	Restoration	Restoration	Restoration	Restoration
URI, Inc.	Rosita	Duval, Texas	1,000,000	Restoration	Restoration	Reclamation	Reclamation
URI, Inc.	Vasquez	Duval, Texas	800,000	Restoration	Restoration	Restoration	Restoration
Uranerz Energy Corporation	Nichols Ranch ISR Project	Johnson and Campbell Wyoming	2,000,000	Producing	Producing	Operating	Operating
Uranium Energy Corp	Goliad ISR Uranium Project	*Goliad, Texas*	1,000,000	Permitted And Licensed	Permitted And Licensed	Permitted And Licensed	Permitted And Licensed
Uranium One Americas, Inc.	Jab and Antelope	*Sweetwater, Wyoming*	2,000,000	Developing	Developing	Developing	Developing
Uranium One Americas, Inc.	Moore Ranch	*Campbell, Wyoming*	500,000	Permitted And Licensed	Permitted And Licensed	Permitted And Licensed	Permitted And Licensed
Uranium One USA, Inc.	Willow Creek Project (Christensen Ranch and Irigaray)	Campbell and Johnson, Wyoming	1,300,000	Operating	Operating	Operating	Operating
Total Production Capacity:			26,975,000				

Notes: Production capacity for 3rd Quarter 2015. An operating status of "Operating" indicates the in-situ-leach plant usually was producing uranium concentrate at the end of the period. Hobson ISR Plant processed uranium concentrate that came from La Palangana. Hobson and La Palangana are part of the same project. ISR stands for in-situ recovery. Christensen Ranch and Irigaray are part of the Willow Creek Project. Uranerz Energy has a tolling arrangement with Cameco Resources. Uranium is first processed at the Nichols Ranch plant and then transported to the Smith Ranch-Highland Operation plant for final processing into Uranerz's uranium concentrate. CPP stands for central processing plant.

Source: U.S. Energy Information Administration: Form EIA-851A and Form EIA-851Q, "Domestic Uranium Production Report."

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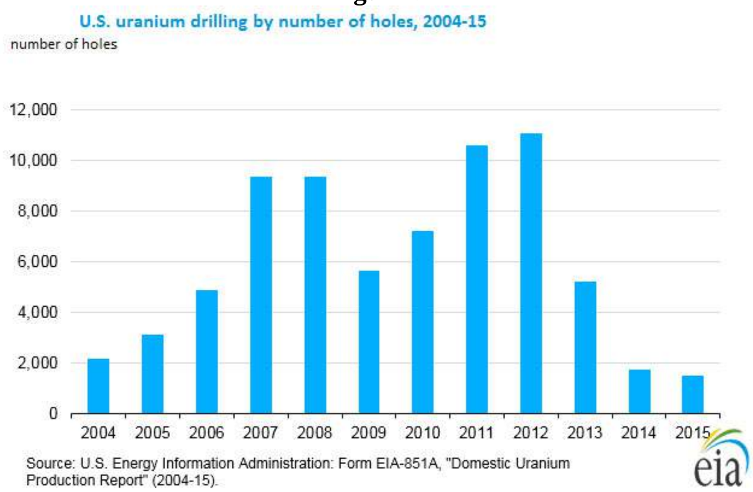
Total uranium drilling in 2015 was 1,518 holes covering 0.9 million feet, amounting to13% fewer holes than in 2014, as would be expected with decreasing uranium prices (see Figure 9). Drilling will increase substantially as the predicted “dramatic” price increases finally occur. If the number of mergers and acquisitions currently underway within the uranium industry is any indication, the industry is preparing to expand production within the next few months or early next year (more).

Figure 9



Recent exploration can be monitored online via the I2M Web Portal (updates), and by using more generalized search terms (here), which will reveal exploration and associated activities for uranium and other commodities as well. Google search results (current) continue to show a multitude of mergers, acquisitions and consolidations within the uranium industry.

Known deposits and some new discoveries occur in 13 U.S. States, with Virginia most notable because of the potential large size of the deposit. Local adversaries continue to obstruct the development of the Coles Hill deposit in Virginia (more). Updates on the Coles Hill project are available via the I2M Web Portal (more). Uranium mining in the U.S. has been conducted in Wyoming, Nebraska, Utah, South Dakota, Texas, Colorado and New Mexico, with numerous other states having some potential (more).

Expenditures for uranium drilling in the U.S. were $29 million in 2015, an increase of 2% compared with 2014 and perhaps related to anticipated production, especially in Wyoming and Texas.

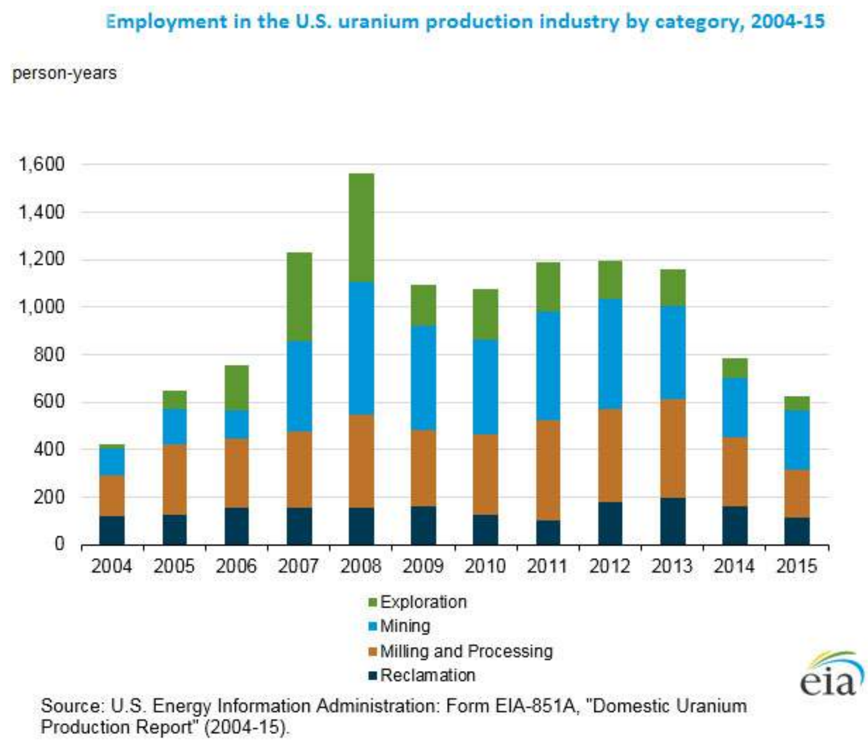
Employment in the U.S. Uranium Industry

EIA (2015) reports that the total employment in the U.S. uranium production industry was 625 person-years in 2015, a decrease of 21% from the 2014 total and the lowest since 2004.

Exploration employment was 58 person-years, a 33% decrease compared with 2014. Mining employment was 251 person-years, and increased 2% from 2014. Milling and processing employment was 200 person-years, a 32% decrease from 2014. Reclamation employment decreased 28% to 116 person-years from 2014 to 2015. Uranium production industry employment for 2015 was in 9 States: Arizona, Colorado, Nebraska, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming.

Figure 10

(EIA – 2016)



SIGNIFICANT FIELD ACTIVITIES IN EXPLORATION AND MINING

Beyond the exploration and mining projects in the U.S., drilling in Canada is likely to be 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. 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.

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 (more). Specifically:

1. NexGen is drilling up huge reserves with high grades at depth (more)
2. Fission has made a major discovery in the Patterson Lake area (more)
3. Top 10 Mines: Canada (1+), Kazakhstan (5), Australia (1), Niger (1), Russia (1), and Nambia (1).

OPERATIONS IN THE U.S.

Ninety-nine nuclear reactors are currently licensed and operating in the U.S., and five are being closed or are in the process of being shuttered. Nuclear plants operate 24/7 and generate about 63 percent of the U.S. carbon-free electricity, but competitive electricity markets do not incorporate these attributes and some plants may be shuttered on economic grounds in competition with the currently low-priced natural gas and coal-burning power plants.

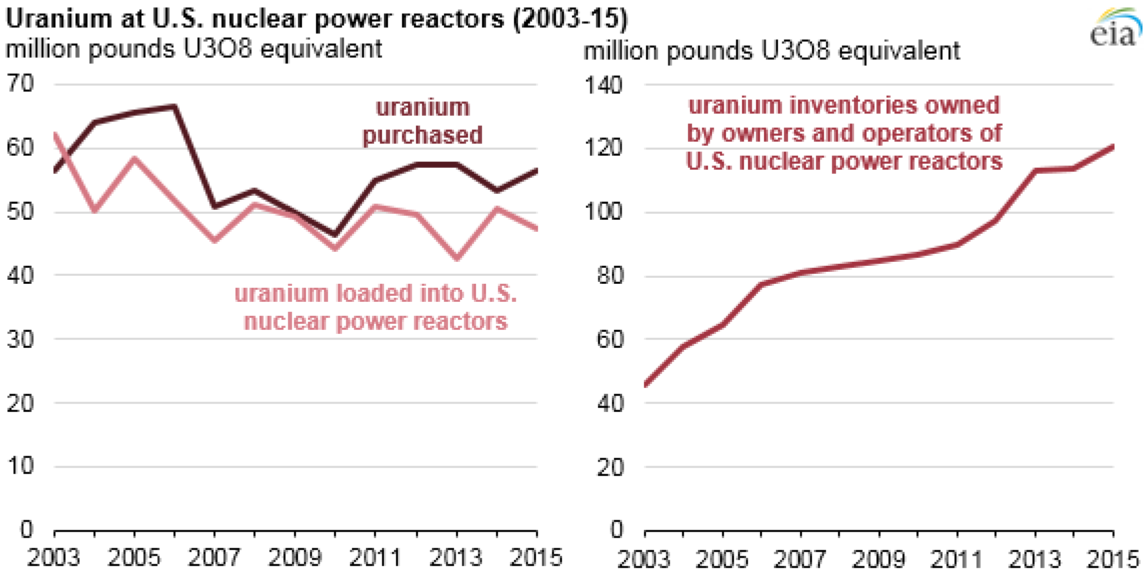
The current technical media are filled with optimism for an expansion of nuclear power (more), which stands in stark contrast to the media of the 1970s, which stampeded the general public away from nuclear power by pandering to their unfounded fear of radiation leaks at Three-Mile Island. The media now has turned to reality in assessing the value of the standard nuclear reactors and of the potential of the new, small modular reactors (SMRs), which will be discussed later in this report.

Both types are known to provide safe, reliable 24/7 electrical production. In the large capacity versions of 500 MW and up, financing is now designed for a facility to operate with upgrading over a period of at least 50 years. Notwithstanding the current un-natural economic restraints created by regulatory circumstances in the U.S., nuclear power continues to generate electricity that is still almost “too cheap to meter,” and natural gas was once cheap enough to flare (more). Coal still is the chief source of energy in the U.S., but its use for burning is finally on the decline. Alternative uses of the vast carbon (graphene) within coal resources are being explored (more) and (more).

But spot prices for uranium have been low for the past few years in part because of uranium inventories held by owners and operators of U.S. nuclear power reactors. From 2004 to 2015, owners and operators of U.S. nuclear power reactors purchased 677 million pounds of uranium, and 592 million pounds were loaded into U.S. nuclear power reactors.

Since 2003, annual uranium purchases have exceeded the amount of uranium loaded into reactors. The amount of uranium fuel loaded into U.S. nuclear power reactors averaged 49 million pounds per year from 2004 through 2015, so uranium inventories totaling 121 million pounds at the end of 2015 could provide more than two years of uranium loadings (see Figure11).

Figure 11



Source: U.S. Energy Information Administration, *Uranium Marketing Annual Report*

Of the 3.6 million pounds of U.S.-produced uranium sold in 2015, 1.5 million pounds were purchased by owners and operators of U.S. nuclear power plants from U.S. uranium concentrate producers. The remaining 2.1 million pounds were sold by U.S. producers to U.S. suppliers and foreign suppliers in 2015. Once the current surplus uranium has been sold off, price rises will no doubt materialize and many exploration companies are counting on them.

SHUTTERING AND DECOMMISSIONING OF NUCLEAR POWER PLANTS IN THE U.S.

Given the advantages of nuclear power, economic factors involving low-price natural gas have shuttered some nuclear plants and left others at risk of being closed. This condition will not likely change until a) the natural gas prices rise substantially, or b) the old gas pipelines within cities create notable additional media events that would tend to drive the general public and regulators away from natural gas and toward nuclear power, even more so than now (more 1) and (more 2, including coal plants).

NUCLEAR POWER PLANT CONSTRUCTION OVERSEAS

Construction overseas continues to increase, aided by Chinese and Russian offers to finance the building and operation of nuclear power plants in India, Bangladesh, the U.K., and other locations, see: (China: more) and (Russia: more). Recent announcements of such construction are reported in the current I2M Web Portal (more).

SMALL MODULAR REACTORS

Small Modular Reactors (SMRs) continue to receive increased attention in 2016, continuing an upward trend in developing SMRs for standby use in case of disasters, for remote areas, including off-world, as well as for operating sector grids in small towns or in large cities where a number of SMRs could be located around the city (more). The TVA is leading efforts toward a rational energy mix (more); see further discussions below (in section on Renewable Energy Systems).

Numerous research and development programs are underway on SMRs by many companies in the U.S. and overseas (more). For additional, updated information and media items on SMRs to date, see (media: more). For technical information on the development and current status of SMRs, see (technical: more). NuScale Power is committing major funding to developing commercial applications of SMRs (more). Bill Gates and others continue to support SMRs searching for the optimum design (more).

SPENT-FUEL STORAGE

There are political indications that the Yucca Mountain facility may still be opened to meet its intended purpose, which is to store nuclear waste from the nation's nuclear power plants, now that the Senior Nevada Senator's influence has been markedly complicated via the recent Nevada elections (here).

Bipartisan support and Republican efforts to reinstate the Yucca Mountain facility are getting some support from a number of sources. Even though the 'store in place" plan is viable, the nuclear power plants are not getting what they have been paying decades for and what has been mandated by law, a secure place to store the nuclear waste (more). The history of the growing support and the opposition against opening the Yucca Mountain facility are being continuously monitored by the I2M Web Portal (more). 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 (more), but other sites are now being considered (more).

OVERALL PERSPECTIVE

The adversaries of nuclear power (and of mining of uranium) continue to apply the same ill-founded and exaggerated claims throughout the world, mostly generated by competing energy interests and by paid commercial adversaries (wind, solar, and associated industries) who are encouraged to be against "climate change", and pass the misinformation meme on to well-meaning, but ignorant people in the U.S. and around the world (more) and (more).

A growing number of prominent professionals on the subject over the years have come to support particular nuclear power projects as the energy of choice for generating electricity throughout the world (more). This is based primarily on the basis that it minimizes damage to Earth's climate; it has been a safe source to operate over more than 50 years without a death or significant radiation exposure to humans (except for Chernobyl (more)).

It is, therefore, incumbent upon industry and government to inform and educate adversaries throughout the world of the realities and need of uranium mining and on the superiority of nuclear power for generating electricity in terms of safety, long-term cost, 24/7 availability, and climate stability (more).

RENEWABLE ENERGY SYSTEMS

Conca (2016) suggests that the TVA understands that the correct energy mix is more than just lower carbon emissions. It is all about grid stability, making sure the power is available whenever it's needed without the use of costly back-up fossil fuel from plants on wasteful standby. Wind has larger and more erratic intermittency than solar and is, therefore, more difficult and costly to integrate, usually requiring natural gas plants to provide grid-backup.

Enter SMRs. SMRs are ideally-suited to help integrate renewables onto the grid without increasing the carbon footprint. While TVA's SMR siting application is not tied directly to a specific reactor, the leading SMR design is Oregon's NuScale power module was designed to integrate completely with renewable energy (more).

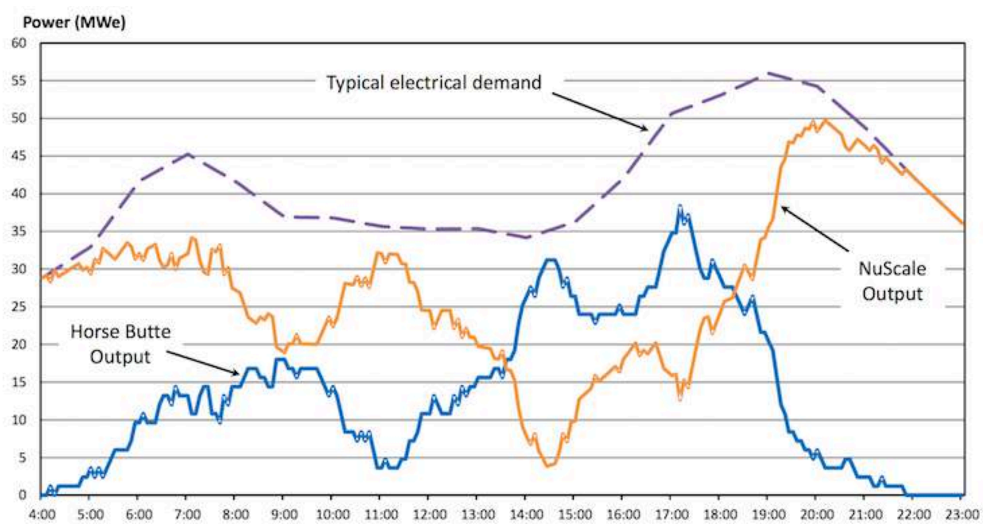


Figure 12 – Typical Grid Support of Renewables add Wind Farm and SMR

An illustration of how a small modular reactor (SMR) would compensate for wind generation variations during load-following of, in this case, the Horse Butte wind farm in Idaho, in order to meet daily electricity demand (Figure 12). SMRs being considered for integrating TVA's growing renewable portfolio (driven by "popular" demand) without using natural gas or wasting of hydropower through losses from long-line extensions (more).

One of the strengths of SMRs is that they can be grouped in a series of smaller reactor modules (aka nuclear batteries) that run independently, allowing the total power output in one or more modules to be varied in response to renewables intermittency in three ways:

- taking one or more SMR units offline for extended periods of sustained solar or wind output,
- adjusting reactor power for one or more modules for intermediate periods to compensate for hourly changes in production by renewables (wind or solar), or
- bypassing one or more SMR unit for immediate response to extremely rapid variations in electrical generation by renewables on the seconds-to-minutes scale.

If the renewable generation surpasses 15% of power output in the U.S. in the next decade, this type of load-following will be critical for maintaining a stable grid. Otherwise, excessive operation and maintenance costs inherent in wind and solar systems will likely become a factor in further expansion.

Ramping up solar within a multi-energy system such as the TVA is also challenging, but for a different reason. Although Tennessee experiences plenty of sunshine, there is little state legislation promoting solar because coal is plentiful, provides jobs, and is relatively inexpensive in the region. Tennessee has a solar rating of "good" meaning that with local and federal subsidies; a 3 kW home solar system costing around $15,000 would pay for itself within 10 years (more). Not only would the homeowner reportedly save over $800 a year on utility bills with such a system, but these generally increase property values by about $10,000 (more), assuming the subsidies are not eliminated.

But TVA also offers incentives, especially in their TVA Generation Partners Program (more), where a program involves a $1,000 plus $0.12/kWh above the base electricity rate, which will reduce years off of the 10-year payback period (more). The State of Washing ton also has a similar plan, but because of the vagaries of the weather both solar and wind needed grid-support to the extent that without the subsidies extracting funds from state and federal budgets, the economics are challenging here as well. Both hydropower and nuclear are marginalized resulting in increasing electricity prices to the general public (more), a common theme becoming prevalent in the U.S. today where renewable energy is forced into the energy selection process by well-meaning political mandate ignorant of the impact on future energy prices and stability of power grid.

In addition, Conca (2016) reports that four Tennessee Valley Authority electricity distributors were recently picked to generate solar power, which the TVA will buy as part of a 2-year pilot program to encourage more solar-power production (more). Plans are underway to build a solar farm that will generate 1.35 MW of solar power that will be collectively supported by a number of individual customers. TVA currently has more than 400 MW of renewable solar power under contract, enough electricity to power more than 216,000 homes. But Google undertook a comprehensive conversion to renewables for their new operations complex in California and found the approach to be economically untenable (more).

Nearly five years after the 2011 tsunami in Japan, even Germany, Sweden, and France are beginning to realize after serious economic evaluations that it would be less expensive to keep their nuclear power plants operating then transition to a wholesale commitment to wind/solar construction for other than remote areas not requiring grid-support. Reliance on brown coal, and large-scale wind/solar systems have neither met climate needs of the former, or in the latter have provided reliable and stable electricity costs (more).

Offshore wind systems do show significant cost advantages but their actual O&M costs are unknown at present. As indicated in previous UCOM reports (2015, pp.12-15), the number of wind and solar pundits continue to flood the Internet with unduly optimistic outlooks promising subsidies for those who can afford to pay the up-front costs involved in renewable conversion.

Only recently does the subject of O&M costs enter the discussion regarding solar O&M: more; and wind O&M: more). Wind is getting mixed reviews (more), even some environmental objections (more). But renewables still do not have established records in O&M within a scaled-up grid; the economics are only attractive with substantial state and federal subsidies. However, one such renewable energy source does appear to have favorable features that are similar to nuclear power. Hydroelectric power plants, involving both dams and pumped storage systems, may be about ready for resurgence in the U.S. and elsewhere in the world (more), but not without some resistance from the usual opponents supporting river wildlife (more).

If the climate is to be a consideration and if the cost of electricity, without local, state, and government subsidies, are to be included in an assessment of the best approach to energy selection, then nuclear power continues to prevail, that is, in balance with natural gas between costs and the environment. Coal is being tolerated because it is perceived by some that there are no other choices even in light of the significant damage to human health and the environment caused by burning coal (plus lignite in Texas and Louisiana, and brown coal in Germany), although lower derived electricity costs of using coal are significant drivers (more).

Further, wind and solar energy projects are still being funded and operated under large subsidies while their operation and maintenance costs remain underreported (more), and (more and more). Serious questions are being raised by independent reviewers on the economic viability of the two energy sources in terms of the generated cost of electricity (more). This is not to say that wind and solar do not have a role to play in energy selection where they are useful (more, pp. 12-15). They are particularly well suited for the small, isolated population centers scattered throughout the high plains and southwest U.S. as only an example.

News items by the local media and blogs supported by solar and wind interests either by commercial, university, or governmental funding express agendas that support the bias with no mention of actual costs, especially O&M costs, see (solar) and (wind). All this appears in the media while news of both the resurgence and death of nuclear power used for generating electricity continue to compete for the attention of the citizens in the U.S. and overseas (nuclear).

THORIUM ACTIVITIES

The U.S. is not the only country that contains thorium resources. According to the USGS, in 2014 exploration and development of rare-earths projects associated with thorium were underway in Australia, Brazil, Canada, Greenland, India, Russia, South Africa, the U.S. and Vietnam (more).

Thorium may be useful not because uranium fuel is getting scarce (it is not) but because when thorium is used in reactors, it produces less waste than uranium. But there are still issues (more).

To review current reports, media items, and other information selected from the I2M Web Portal thorium database, see (more).

RARE-EARTH ACTIVITIES

At present, rare earth resources have been discovered in about 35 countries and regions around the world, with total reserves of 130 million tons, of which 42.3% are owned by China alone (more). In order to protect and rationally develop superior resources, China has adopted a cap-control policy for rare earth exploitation since 2006. Hence the rare earth ore production in China suffered a continuous decline from 2010 to 2013. In 2014, the Chinese government raised the upper limit, a move that helped drive the rare earth output rise 14.5% year per year to 95,000 tons, amounting to about 86.4% of the global total.

China has not only the largest proportion of the total global rare-earth resources in production on Earth, but also the most extensively developed total supply chain for rare earths, and perhaps most important of all, the overwhelming majority of rare earths R&D implemented by the largest group of scientists and engineers devoted to rare earths studies and manufacturing on Earth. Some evidence exists that 90-95% of all rare earth R&D today takes place in China (more). Thus, it would appear that the rare earths industry is much more important to China than it could ever be to any other nation at the moment.

To review other current reports, media items, and other recent information selected for the I2M Web Portal rare-earth database, see (media: more) and U.S. Geological Survey research: (more).

URANIUM & RARE EARTH UNIVERSITY RESEARCH

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

Interest in uranium, thorium, and rare-earth element (REE) research has continued to decrease due to the slump in commodity prices. Of the 44 grants awarded for research in economic geology by the Society of Economic Geologists Foundation (SEGF) and the SEG Canada Foundation (SEGCF), none were for uranium, thorium or REE related research. Despite the lack of new grant funding, there are research projects of interest still being conducted at some of the U.S. universities. Economic geology of REE deposits continues to attract more research effort than uranium or thorium deposits.

At the Colorado School of Mines (CSM):

John DeDecker is continuing his Ph.D. research project, "Alteration associated with basement faults in the Athabasca Basin, Saskatchewan" which is supported by Cameco.

Timothy Wyatt's, "Residence of uranium in roll-front deposits: A case study".

Mike Berger continues to work on "Characterization of alkaline igneous rocks and alteration at the Pajarito Mountain REE-Zr deposit, Mescalero Apache Indian Reservation, New Mexico" (more). Dr. Alexander Gysi has recently joined the faculty at CSM. His research interests are in the areas of REE mineral deposits and thermodynamic properties of minerals.

Dr. Brent A. Elliott (of University of Texas at Austin) is conducting research related to hyperspectral REE signatures, and REE's in volcanic and subvolcanic rocks scattered across the Trans-Pecos region, including Round Top at Sierra Blanca (which will be in production soon (more)). The preliminary economic study shows favorable results (more).

Virginia McLemore (of New Mexico Tech) is working with students on a number of uranium reclamation projects and has drilled at Apache Mesa on the Jicarilla Indian Reservation in Rio Arriba County looking for REE, U, Th, Nb in Cretaceous beach placer sandstone deposits. Results will be published this year. In 2105, she produced a number of publications on REE deposits in New Mexico:

McLemore, V.T., Dunbar, N., Heizler, M., and Rämö, O.T., 2015, Origin of the REE-bearing Cambrian-Ordovician episyenites and carbonatites in southern and central New Mexico, USA: Geological Society of America, Abstracts with Programs, v.47, no. 7, p. 814-815.
also see http://geoinfo.nmt.edu/staff/mclemore/projects/documents/Riggins_SEG.pdf

McLemore, V.T., 2015, Geology and Mineral Resources of the Laughlin Peak Mining District, Colfax County, New Mexico: New Mexico Geological Society, Guidebook 66, p. 277-288,

https://nmgs.nmt.edu/publications/guidebooks/papers.cfml?v=66&file=66_p0277_p0288.pdf (REE, Th, U)

McLemore, V.T., 2015, Rare Earth Elements (REE) Deposits in New Mexico: Update: New Mexico Geology, v. 37, p. 59-69, http://geoinfo.nmt.edu/publications/periodicals/nmg/current/home.cfml

McLemore, V.T., 2015, Mineral deposits associated with Tertiary alkaline igneous rocks in New Mexico: Society for Mining, Metallurgy, and Exploration, 2015 Annual meeting preprint 15-084, 13 p. http://geoinfo.nmt.edu/staff/mclemore/projects/documents/15_084.pdf

Suggestions for Research for Sedimentary Uranium Deposits

There have been a number of new concepts developed in geology in the last 30 years that could be applied to the exploration for sedimentary uranium deposits. There is a need for exploration techniques that could be used in frontier areas or areas where the roll-front model would possibly overlook economic uranium deposits in sedimentary rocks.

There are significant uranium deposits in the tabular-hosted sandstone deposits found in Triassic and Jurassic strata of the Colorado Plateau as well as deposits found in carbonates (Todilto limestone and breccia-pipe deposits in Arizona). Identifying source rocks and understanding migration paths or paleohydrogeology could be utilized to predict the presence of uranium deposits that would be missed using the roll-front model.

Sequence stratigraphy, which has become a tremendous tool for improving the predictive aspects of petroleum exploration, could also be used to develop strategies for uranium exploration. Sequence stratigraphy analyzes the sedimentary response to changes in base level. Base level is defined as the surface at equilibrium between erosion and deposition. In marine and coastal environments, sea-level fluctuations are usually the main influence on base level. In upland areas, tectonic activity can be the major factor in changing the base level.

A drop in base level caused by either a drop in sea level or tectonic uplift may cause a significant drop in groundwater table elevations and introduction of uranium rich oxidizing groundwater into sediments with reducing conditions (carbonaceous material, pyrite). The uranium will then precipitate under reducing conditions (low oxygen) which will precipitate the uranium forming a deposit of uranium. The response to a base-level drop in the sedimentary record is often an unconformity in the fluvial valley and a sequence-bounding paleosol or geosol in the higher areas of the fluvial system.

In the late 1970's, researchers at the Texas Bureau of Economic Geology found that uranium had been leached from the vadose zone of a paleosol developed in the Catahoula Formation and proposed that this paleosol and similar paleosols could be source rocks for uranium deposits. This subject is discussed in more detail in association with Figures 6 and 7 earlier in this report.

Detailed academic stratigraphic studies of the Chinle and Morrison Formation in the Colorado Plateau and the White River Group in the High Plains in recent years have identified significant paleosol development within these sequences which could be studied further to determine if these paleosols acted as source rocks for the uranium deposits found within these formations or stratigraphically below these formations.

Campbell and Biddle (1977b, pp.6-10) conducted some early work on hydrochemical issues around the Morton Rach mine in Wyoming. Modeling (reconstruction of) the paleohydrogeology of these formations could then be used to determine if the observed distribution of economic uranium deposits could be "recreated" using modern groundwater flow models. Understanding sources of uranium coupled with modern modeling techniques could lead to successful exploration of uranium deposits where no surface expressions or outcropping lithologic manifestations exist.

URANIUM & RARE EARTH STATE/FEDERAL GOVERNMENT RESEARCH

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

Additional uranium research subjects investigated by the U. S. Geological Survey are available for review (more).

Additional rare-earth research subjects investigated by the U. S. Geological Survey are available for review (more).

AMBIENT RADIATION IN THE ATMOSPHERE

On the basis that the impact of radiation is difficult to understand for many, we are continuing a new resident section to the UCOM report for this Annual Report to provide some clarity regarding the minimum safe radiation exposure to humans (more). This matter has also been treated in some detail earlier by this committee (more, pp. 171-177), and even (more).

Conca (2016) reports that, aside from exposure to the Sun causing skin cancers and to radon causing lung cancer to underground mining personnel who smoke, it is very rare for anyone to be hurt by any dose of radiation. Contrary to the hype and fear pandering by the media on Fukushima (more), and even Chernobyl, the observable radiation health effects from both accidents were small. In the case of Fukushima, it was as close to zero as one can get. In the case of Chernobyl, although significant, it was much smaller than originally anticipated (more).

The reason for this is that almost everyone has been using the wrong model to predict health effects from radiation at these levels, and only recently have the global health, nuclear and radiation agencies realized that error and are moving to correct this matter. However, as with most scientists, this change has been slow. And, the matter is also very political since it involves extensive investments over many years. But the implications are enormous.

The latest scientific society to make clear that model applied over the years is not appropriate as suggested by probably the most qualified independent group to understand this issue, the Health Physics Society. It is the scientific society that includes radiation protection scientists. And they recently put out a revised position statement on Radiation Risk In Perspective (more). In it, they advise against estimating health risks for people from exposures to ionizing radiation that are anywhere near natural background levels because statistical uncertainties at these low levels are great. In other words, any possible adverse health effects resulting from radiation doses below 10,000 mrem (100 mSv) are not detectable.

Background radiation across the Earth varies from 3 mrem/yr (0.03 mSv/yr) over the oceans to 10,000 mrem/yr (100 mSv/yr) in areas of high elevation made up of granitic rocks on the surface. Thus, it is not surprising that populations subjected to radiation levels of 10,000 mrem (100 mSv) or below, show radiation effects that are not statistically different from zero. Cancer will develop naturally with no contribution from radiation. If you subject a large population to radiation levels ten times their normal radiation levels, 40,000 ± 1,600 will develop cancer over their lives (more). There will be no difference.

Of course, there could be a few dozen cases hiding in that huge error bar number, that plus or minus 1,600 is within the margin of error , but by definition those will be statistically insignificant and should not be any cause for concern. They're too few to ever be measured. The concern should be for the 40,000 natural cancers, the direct causes of these are the subject of ongoing, intensive medical research (i.e., Jaworowski (2010), WCR (2016), and others).

The reason for this 60-year overreaction is this incorrect model, called the Linear No-Threshold dose hypothesis (more). LNT has been used in radiation protection to quantify radiation exposure and set regulatory limits. First put forward after WWII, LNT assumes that the long term, biological damage caused by ionizing radiation (primarily the cancer risk) is directly proportional to the dose … increase the dose, increase the risk, increase the cancers, increase the deaths. But this model just sums exposure to all radiation, without taking into account dose levels or dose rates, or the fact that organisms have immune systems that are very effective at repairing cellular damage from normal, natural doses of radiation.

Conca (2016) provides additional compelling evidence regarding the "low dose" impact. He emphasized that this model was used incorrectly to estimate public health effects. Hundreds of thousands of people were unnecessarily evacuated because of the overestimation of adverse health effects by radiation exposure as predicted by the LNT, incurring a much larger risk from the perils of the evacuation. As a result, many thousands of deaths occurred, not from radiation, but from panic, depression and alcoholism. This applies to all of the incidents at Three-Mile Island (1979), Chernobyl (1986), and at Fukushima (2011), all created by a fear-pandering media.

The damage at the Fukushima Daiichi Power Plant following the devastating tsunami in Japan has proven costly in many ways , politically, economically and emotionally. But the feared radiation-induced cancer and death is not occurring.

According to UNSCEAR, no radiological health effects have resulted from the Fukushima incident in the public, neither cancers, deaths nor radiation sickness. No one received enough dose, even the 20,000 workers who have worked tirelessly to recover from this event. A recently published paper by Cuttler and Welsh (2015) in the *Journal of Leukemia* pointed to two important aspects of this issue:

1. UNSCEAR unequivocally reported that "Radiation exposure has never been demonstrated to cause hereditary effects in human populations," a finding supported by recent research (more), and
2. the health data from Hiroshima on about 96,800 humans suggest there is an acute radiation threshold at about 50 rem (500 mSv) for excess leukemia incidence. This is consistent with the conservative threshold dose of 10 rem (100 mSv) for all cancers.

The large numbers of cancers and deaths predicted for Chernobyl and for Fukushima that have flooded the media were all generated by this incorrectly-applied model. It is now up to the scientific community, which generally avoids political controversy, to weigh in on this subject and decide whether being conservative is worth the pain and suffering it will cause to the public if (or when) another incident occurs.

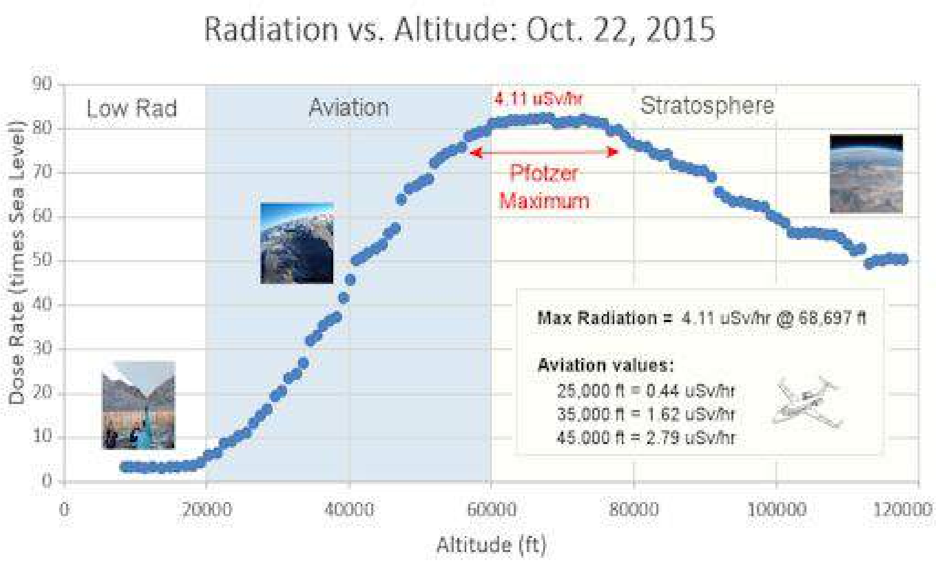
As indicated in previous UCOM reports, radiation (from cosmic ray) measurements are being made on regular flights of space-weather balloons (more). Approximately once a week, *Spaceweather.com* and the students of *Earth to Sky Calculus* fly space weather balloons into the stratosphere over California and elsewhere (more). These balloons are equipped with radiation sensors that detect cosmic rays, a form of space weather. Cosmic rays can seed clouds (more), trigger lightning (more), and penetrate commercial airplanes (more). Their measurements show that a person flying back and forth across the continental U.S., just once, can absorb as much ionizing radiation as 2 to 5 dental X-rays.

As an example of the information available on *Spaceweather.com*, a situation report for October 30, 2015 is presented below:

Situation Report -- Oct. 30, 2015	Stratospheric Radiation (+37° N)
Cosmic ray levels are **elevated** (+6.1% above the Space Age median). The trend is **flat**. Cosmic ray levels have increased **+0%** in the past month.	Sept. 23: 4.12 uSv/hr (412 uRad/hr)
	Sept. 25: 4.16 uSv/hr (416 uRad/hr)
	Sept. 27: 4.13 uSv/hr (413 uRad/hr)
	Oct. 11: 4.02 uSv/hr (402 uRad/hr)
	Oct. 22: 4.11 uSv/hr (402 uRad/hr)

Figure 13 is the plot from the October 22, 2015 flight. The plot below shows the data recorded for increasing altitude vs. radiation dose rate during the balloon flight, which reach a maximum altitude of 120,000 feet above sea level. Figure 13 also shows the aviation range of radiation exposure.

Figure 13



Radiation levels peak at the entrance to the stratosphere in a broad region called the "Pfotzer Maximum." This peak is named after physicist George Pfotzer who discovered it using balloons and Geiger tubes in the 1930s. Radiation levels there are more than 80 times those at sea level and then decreases to 50 times. The reason for this decrease is likely related to the differing position of the Earth's geomagnetic field over California, New Hampshire, and Oregon (more), see Figures 14 though 17.

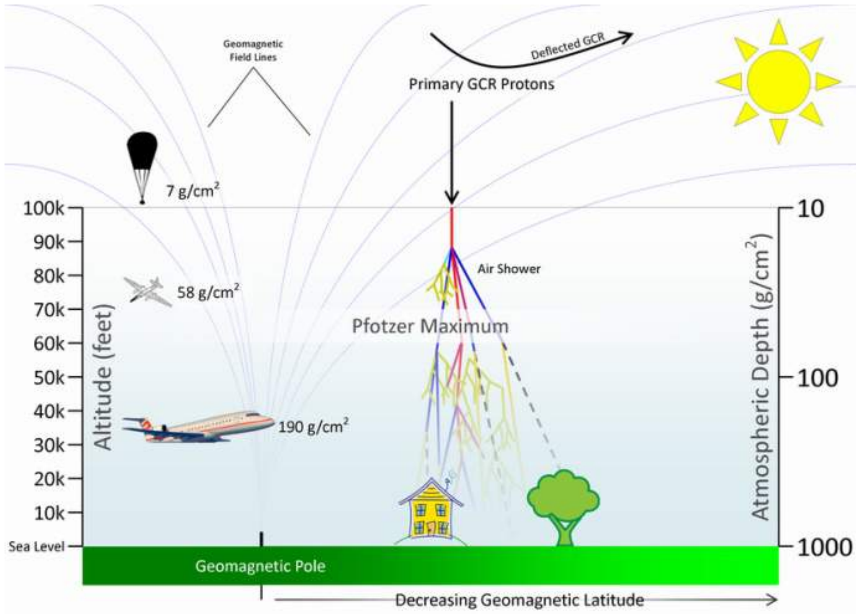


Figure 14 – Location of the Pfotzer Maximum Radiation
(Spaceweather.com)

Figure 15 – Activities During a Balloon Launch
(Spaceweather.com)

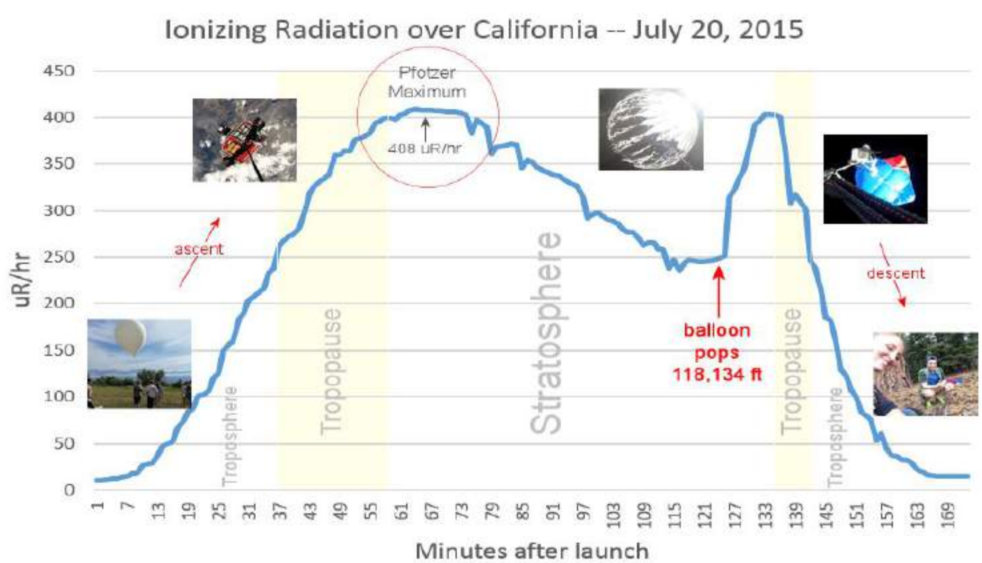


Figure 16 – Difference in Maximum Radiation
(Spaceweather.com)

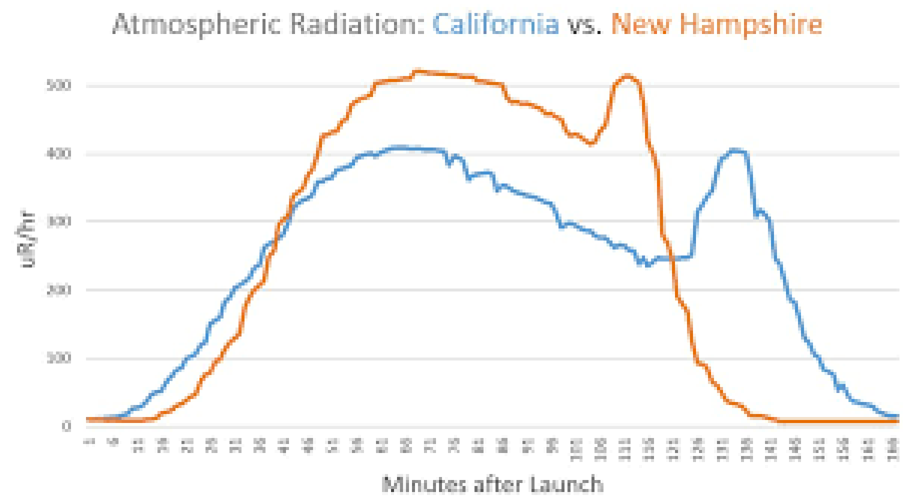
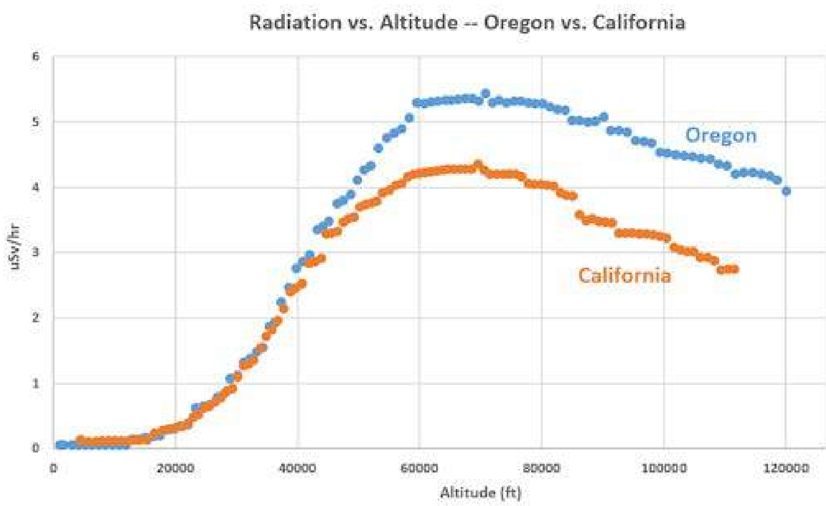


Figure 17 - Difference in Maximum Radiation
(Spaceweather.com)



From ground level to 40,000 feet, the two curves are almost indistinguishable. In terms of radiation, California and Oregon are much the same at altitudes where planes fly. Above 40,000 feet, however, the curves diverge. Peak radiation levels detected in the stratosphere over Oregon were more than 25% higher than California.

At the entrance to the stratosphere, about 70,000 feet above Earth's surface, the broad layer of ionizing radiation called the Pfotzer Maximum extends from about 55,000 feet to 75,000 feet in altitude and is monitored to evaluate its response to solar storms. Most airplanes fly below it; satellites orbit high above it.

Energy releases during large thunderstorms that recently have been identified are known as Jets, Sprites and Elves appear to be in the middle and above the Pfotzer Maximum zone but they also may contribute energy to the Earth's geomagnetic system in some way (see Figure 18).

Note in Figure 13 that the bottom of the Pfotzer Maximum is near 60,000 ft. This means that some high-flying aircraft are not far from the zone of maximum radiation. Indeed, according to the October 22nd measurements, a plane flying at 45,000 feet is exposed to 2.79 uSv/hr. At that rate, a passenger would absorb about one dental X-ray's worth of radiation in about 5 hours. For context of such radiation; see Radiation Dose Chart (here).

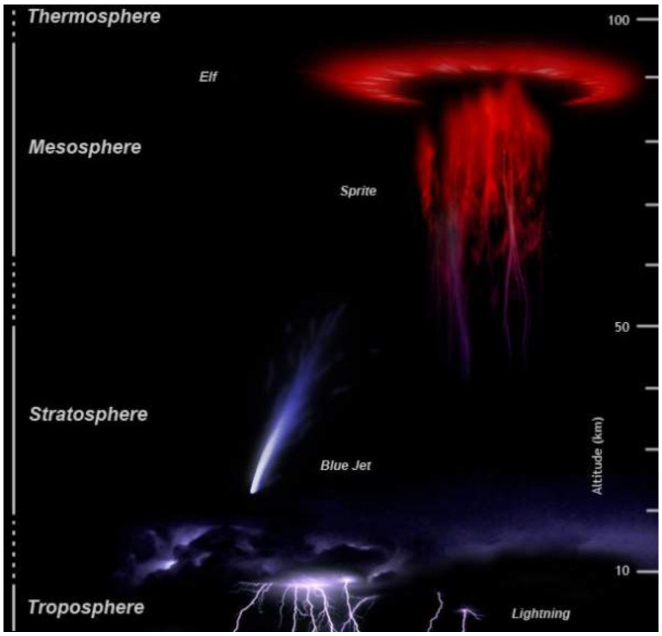


Figure 18 – Sprites and Jet "Lightning" above Large Thunderstorms (HAARP)
(Click to Enlarge Graphic)

The radiation sensors onboard the 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).

A list of references for additional reading on radiation is presented below:

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