Nuclear Fuel Exploration, In Situ Recovery, and Environmental Issues in context with the National Energy Needs through Year 2040

Texas Commission on Environmental Quality Conference & Trade Fair
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By

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and

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Version 2.7
• Purpose of Presentation

✓ To Increase Communications between the General Public, Regulatory Agencies (TCEQ, RRC, TDSHS) and the Uranium Industry,

✓ Encourage Research by BEG and TWDB on Issues Important to Uranium Industry and to the General Public,

✓ Encourage Research on Health and Regulatory issues important to the General Public,

✓ Encourage Recruiting Graduates and Professionals Interested in Working in the Uranium Industry, and

✓ Encourage Geology Graduates, Academics & Others Working in Natural Resources Development in Texas to Obtain a State License as a Professional Geoscientist.
• Coverage of Topics

- **Introduction to Uranium Exploration & Recovery:**
  - The Old, The Improved, and The Missing
    - Techniques of the 1970s
    - Environmentally Friendly Approach
    - A Missing Generation of Uranium Professionals
  - Permitting Guides
    - Background Surveys
    - Surface Water & Ground Water (Water Wells)
    - Regional Hydrogeological Setting
• Coverage of Topics

- Uranium Exploration & Recovery & Health
  - In Texas
  - In Colorado
  - Numerous Studies

- Community Outreach
  - Project Restoration Histories

- Project Economics & Yellowcake Processing

- Nuclear Power: Present Usage

- Alternative Energy Resources: Solar, Wind & Geothermal Energy

- Predictions: 2008 to 2040
Geology of Uranium Occurrences in Texas

Roll Front in Open Pit Wall, Texas (of 1970s)

@ Kingsville Dome, 2007

After: Dickinson & Duval, 1977 in Geology of Alternate Energy Resources, Published by Houston Geological Society
The 1975 Concept of the Biogeochemical Cell in a Roll-Front

Diagram showing the flow of geochemical processes in a roll-front environment, including:
- Calcite precipitates
- Unoxidized and oxidized sands
- pH increase and decrease
- Biochemical sulfate reduction by Desulfovibrio
- Pyrite oxidation by ferric sulfate
- Thiobacillus ferrooxidans biochemically converting to ferric sulfate
- Ferrous sulfate and sulfuric acid
- Uranium and vanadium oxidized and mobilized
- Hydrolysis to sulfuric acid and ferric hydroxide
- Eh increases and decreases
- Uranium reduced stable
- Vanadium reduced stable
- Fermentation of cellulose, lignin & other organic material by Clostridium Cellulosae - Dissolvens

After Rackley, 1975
Roll Front in Open Pit Wall, Wyoming (1970s)

Heavily Oxidized

Roll-Front

Oxidation Front

Uranium Ore
Texas Uranium Occurrences Known by the Mid-1970s:

- Outcrops
- Shallow Ground Water
- Proximity of Catahoula Tuff
- Surface Pits
After: Eagle & Weeks, 1975

- New Occurrences:
  - Deeper
  - Fault Related?
  - Salt-Dome Related
  - Other Sources?
  - Other Reductants
Uranium Mineralization in the Oakville Formation

After Galloway, et al., 1979
• Uranium Mineralization in the Oakville Formation

After Galloway, et al., 1979
• Uranium Mineralization in the Goliad Formation
• Exploration Guides

Understand Mineralization in 3 Dimensions

✓ Number & Location of Drill Holes

✓ Number of Core Samples

✓ Geological Logging

✓ Geophysical Logging
• Exploration Guides
• Standard Rotary Drilling
• Coring Uranium Mineralization
Guide to Locating Oxidized Boundary and Uranium Mineralization:

- Find Ox-Reduction Boundary
- Explore Along Boundary
- Step in – Step out Drilling
- Develop Character of Local Mineralization

After Campbell & Biddle, 1977
Geology of Alternate Energy Resources
Houston Geological Society
• Geophysical Well Logs: Natural Gamma, SP and Resistivity

From: Century Geophysical Corporation
- **New Equipment:**
  - Neutron Logging
  - Supports Natural Gamma Logging in Calculating Reserves
  - Spectral Logging?
  - Additional Logging Equipment?
• In-Situ Recovery of Uranium
Alta Mesa Uranium Recovery Operations

Oxidized Zone

Reduced Zone
• Typical Well Field and Plant Layout
• Typical Layout of Injection and Production Well Field
• Typical Layout of Injection and Production Well Field

Collector Station

To Loading Dock

In Situ Recovery Operations
• Injection Fluids – Light Acids

Liquid O₂

Heat Exchangers
• Permitting Guides

✓ Background Sampling Water Wells
✓ Designated Monitoring Wells
✓ Regional Ground-Water Settings
✓ Also Use in Exploration Programs
- Regional Hydrochemistry: Hydrochemical Facies?

After Smith, et al., 1982
• Regional Hydrochemistry: Hydrochemical Facies?
• Monitoring Wells:
  Monitoring Shallow & Deep Aquifers
• Monitoring Wells: Periphery Sites
Uranium Exploration & Recovery & Health?

- In Texas
- In Colorado
- Numerous Studies:

http://www.mdcampbell.com/PUBMEDSURVEY.pdf
### Table 3

Mortality due to all types of cancer, all ages and sexes combined over four time periods, 1950–2001, in Karnes County and in the four control counties. (‘Obs’ stands for ‘Observed’.)

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Obs</td>
<td>SMR&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Obs</td>
<td>SMR&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Obs</td>
<td>SMR&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Karnes County</td>
<td>267</td>
<td>0.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>331</td>
<td>0.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>279</td>
</tr>
<tr>
<td>Control counties</td>
<td>799</td>
<td>0.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1102</td>
<td>0.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>818</td>
</tr>
<tr>
<td>RR&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.0</td>
<td>0.9</td>
<td>1.1</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> SMR is the observed number of cancers divided by that expected based on rates within the general population of the United States.

<sup>b</sup> Estimated RR taken as the ratio of the SMR in Karnes County with that in the four control counties.

<sup>c</sup> p < 0.05.

• Human Health & Uranium Recovery

Figure 1. A map of South Texas containing Karnes County and the four control counties (Frio, La Salle, DeWitt and Goliad). The dots in Karnes County represent the prior location of 43 mines and 3 mills (Railroad Commission of Texas, Surface Mining and Reclamation Division map).

• Environmental Issues & New Perspectives

Re-Writing & Updating Regulations:
  Texas Railroad Commission Uranium Exploration Area Permits
  Texas Dept. of State Health Services ISR for Plant,
  Texas Commission on Environmental Quality
  1. UIC Aquifer Exemption & Class III Permits,
  2. Production Area Authorization (PAA) for Recovery Operations &
  3. Class I UIC Nonhazardous Well Permit for Wastewater Disposal
• Environmental Issues & New Perspectives

Regulations (Cont’d)

Texas Commission Environmental Quality

4. Clean-ups of Releases & Spills in Well Field and Pipelines.

Texas Parks & Wildlife &
Texas Historical Office

U.S. Army Corp of Engineers

U.S. Environmental Protection Agency
Drinking Water Aquifer Exemptions

U. S. Mine Safety and Health Administration
Recovery & Processing Operations Safety
Environmental Issues & Perspectives

New Perspectives: Not “Cookie-Cutter Functions”

A. “While the aquifer may contain suitable drinking water quality, the area of the aquifer containing uranium mineralization was naturally contaminated by biogeochemical processes long before humans could drill water wells into the aquifer.”

B. “Baseline environmental studies are essential to provide reasonable in-situ recovery closure guidelines.”
• Environmental Issues & Perspectives

New Perspectives:
Baseline Studies Involve:

1. Physical Characteristics, such as: topography, geology, hydrology/hydrogeology, soils, air quality, radiological background, weather/climate information, etc.

2. Biological Characteristics, such as: flora and fauna (terrestrial and aquatic), endangered species (if present), radiological sampling of biota, and

3. Socio-Economic Characteristics, such as: analyses of local populations, employment, resources such as agriculture, fishing, tourism, archeology, and historical information.
• Environmental Issues & Perspectives

Issues to be Anticipated:

✓ Type of Solutions Used in In-Situ Recovery of Uranium?

✓ What is a Reasonable Clean-Up Goal?

✓ What to do about Abandoned Wells?

✓ Best way to Dispose of Wastewaters?

✓ Company Employees Trained in Handling Radioactive Materials?

✓ Have all Water Wells been Sampled in Immediate Area?

“A Strong Community-Relations Program should be an Integral Part of Management’s Function”
Community Outreach

• Talk with Community about Technical Issues

• Rumors & Falsehoods

• Conflicting Agendas

• Positive Features of Uranium Development

• Combating Media Bias Program:
  http://i2massociates.com/downloads/I2MAREviews/
## Environmental Issues & New Perspectives

<table>
<thead>
<tr>
<th>Operation</th>
<th>Status</th>
<th>County</th>
<th>Regional Aquifer</th>
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<tbody>
<tr>
<td>Caithness – McBride</td>
<td>G.W.Restored/Plugged/D&amp;D</td>
<td>Duval</td>
<td>Oakville</td>
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<tr>
<td>Chevron – Palangana</td>
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<td>Duval</td>
<td>Oakville</td>
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<td>Cogema – Holiday</td>
<td>G.W.Restored/Plugged</td>
<td>Duval</td>
<td>Goliad</td>
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<td>Cogema – El Mesquite</td>
<td>G.W.Restored/Plugged</td>
<td>Duval</td>
<td>Catahoula</td>
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<tr>
<td>Cogema – O’Hern</td>
<td>G.W.Restored/Plugged/D&amp;D</td>
<td>Duval</td>
<td>Goliad</td>
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<tr>
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<td>Conoco- Trevino</td>
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<td>Live Oak</td>
<td>Goliad</td>
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<td>Everest – Tex-1</td>
<td>G.W.Restored/Plugged/D&amp;D</td>
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<td>Oakville</td>
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<tr>
<td>IEC – Pawnee</td>
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<td>Bee</td>
<td>Oakville</td>
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<td>Mestena – Alta Mesa</td>
<td>Operation</td>
<td>Brooks</td>
<td>Goliad</td>
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<tr>
<td>URI – Benavides</td>
<td>G.W.Restored/Plugged/D&amp;D</td>
<td>Duval</td>
<td>Catahoula</td>
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<tr>
<td>URI – KVD</td>
<td>G.W. Restoration/Operation</td>
<td>Kleberg</td>
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<td>URI – Vasquez</td>
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<td>Duval</td>
<td>Goliad</td>
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<tr>
<td>U.S.Steel - Boots</td>
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<td>Live Oak</td>
<td>Oakville</td>
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<tr>
<td>U.S.Steel - Burns</td>
<td>G.W.Restored/Plugged/D&amp;D</td>
<td>Live Oak</td>
<td>Oakville</td>
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<td>U.S.Steel - Clay West</td>
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<td>G.W.Restored/Plugged/D&amp;D</td>
<td>Live Oak</td>
<td>Oakville</td>
</tr>
</tbody>
</table>
• Uranium Production & Economics

✓ Like Oil & Gas, Guided by the Sale Price of Yellowcake,

✓ Controlled by Recovery Efficiencies,

✓ Affected by Plant Operations, and

✓ Affected by Delivery Options Available at the Mill.
• Yellowcake Product

Approximately 880 pounds of yellowcake / BBL
At Market Price of $100 / #
$88,000 / BBL
“In-situ recovery of uranium is a special type of environmental remediation where a natural contaminant is removed from an aquifer, treated by processes similar to common water-softening equipment, and put to beneficial use as an energy source.”
After Yellowcake?

Cameco, 2007
Uranium Research

- 1970s Technical Literature
- Company Records
- NURE Records
- Find the Missing Generation

Surface-Sediment Analysis

Thin-Section Analysis
• Uranium Field Work

✓ Conducting Outcrop Analysis

✓ Conducting Field Reconnaissance

✓ Sampling Environmental Monitoring Wells
Assessment
Safety Record,
Economic Advantage, Jobs,
Technology, Management

Anti-Nuclear Power?

Risk
Comparative Analysis
w/ Other Types of Risk:
NIMBY - Industry, Local, etc.

Fear
Weapon of War,
Hollywood &
Press Media
The U.S. Power Grid: Night Lights Tell the Story
What about Nuclear Waste Management?

Fear
Exposure?
Drinking Water?
Hollywood
&
Press Media

Assessment
Safety Record, Good Science
New Technology, Improved Management

Risk
Comparative Analysis
w/ Other Types of Risk:
NIMBY - Industry, Local, &
w/ International Solutions.
...And there are always disagreements....
But What about Solar Power?

Source: NEI
But What about Wind Power?

Source: NEI
Land Needed by Wind or Solar Energy to Match Annual Nuclear Energy Production*

Wind Turbines

Area equal to Minnesota

Solar Cells

Area equal to West Virginia

* 768 billion kilowatt-hours

Source: NEI
What about Geopressured Geothermal Resources?

After Erdlac, 2007
What about New Sources of Power?
What about the Economics?

<table>
<thead>
<tr>
<th>Technology</th>
<th>Expected Capacity Factor (%)</th>
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<tbody>
<tr>
<td>Coal</td>
<td>71</td>
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<tr>
<td>Nuclear</td>
<td>90</td>
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<tr>
<td>Geothermal</td>
<td>86 - 95</td>
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<tr>
<td>Wind</td>
<td>25 - 40</td>
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<tr>
<td>Solar</td>
<td>24 - 33</td>
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<td>Natural Gas Combustion</td>
<td>30 - 35</td>
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<tr>
<td>Turbine</td>
<td></td>
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<tr>
<td>Hydropower</td>
<td>30 - 35</td>
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<tr>
<td>Biomass</td>
<td>83</td>
</tr>
</tbody>
</table>
What about Present Usage Energy Resources?
What about Produced CO₂?
...And there are always disagreements....

global warming over the years

Retreating Ice Sheets:
As temperatures soared, the massive ice sheets that remained from the last period of glacialization retreated to their current position.

Source: AP
...And there are always disagreements....

Recent Global Temperature Changes:
Temperature change in the last century has been measured in respect to a long-term median temperature. Data shows a warming trend in the last 50 years.

Source: U.S. National Climatic Data Center
...And there are always disagreements....

**global warming over the years**

**Average Temperature in Greenland:**
By studying deep samples of ice taken from Greenland and other areas, researchers have been able to understand historical climate changes throughout the years. This graph shows the average temperature in Greenland during the last 20,000 years.

*Source: AP*
• Checks and Balances

Power Industry

Adversarial Groups

State & Federal Regulatory Agencies

Nuclear
Geothermal
Natural Gas
Alternative Energy Sources

We are in this together; united we stand, divided we fall...
Today's Paradyme

Estimates of 21st Century World Energy Supplies:
Billion Barrels Oil Equivalent
Our Predictions: 2008 to 2040*

* Will Change as Technical Breakthroughs Impact Our Predictions

1) Transition Over 30 years from Using Coal to Nuclear Power to Supply the U.S. Power Grid,

2) Remote Favorable Areas for Solar and Wind Will Be Permitted into Periphery of U.S. Power Grid,

3) Natural Gas to Remain Important for Years to Come,

4) Geothermal May Increase by 10% of Power Needs or Better in Texas and Western U.S.
Selected References


Selected References (Continued)


Note: For an online version of this presentation (with links), see: [http://www.mdcampbell.com](http://www.mdcampbell.com) (C&A NEWS).
Biographies

• Michael D. Campbell, P.G., P.H., serves as Managing Partner for the firm, M. D. Campbell and Associates, L.P. in Houston, Texas. He has a strong professional history in major international engineering and uranium mining companies such as CONOCO Mining, Teton Exploration, Div. United Nuclear Corporation, and Texas Eastern Nuclear, Inc. during the 1970s and 1980s, and such as Law Engineering, DuPont, and others in environmental projects from the 1980s to the present. Mr. Campbell has over 40 years of mining, minerals and environmental project experience and has published three technical books on uranium and other natural resources, and numerous associated reports, technical papers, and presentations in the U.S. and overseas. Mr. Campbell is a graduate of The Ohio State University with a Bachelors Degree in geology and hydrogeology, a Masters Degree from Rice University in geology and geophysics, and was elected a Fellow in the Geological Society of America. He was a Founding Member in 1977 of the Energy Minerals Division of AAPG and presently serves as Chairman of the Uranium Committee. He is a Licensed Professional Geoscientist in Texas and in other states. For additional information, see his CV at: http://www.mdcampbell.com/mdcCV.asp.

** Henry M. Wise, P.G., has more than 30 years of professional experience in geological, uranium exploration and development and environmental remediation. His experience includes the exploration and in-situ recovery of roll-front uranium deposits in South Texas where he was responsible for the delineation and production at the Pawilk Mine for U.S. Steel. He also has substantial experience in ground-water remediation projects in Texas. Mr. Wise is a graduate of Boston University and obtained as Master's Degree from the University of Texas at El Paso in geology. He was a Founding Member in 1977 of the Energy Minerals Division of AAPG and is a member of the Uranium Committee. He is a Licensed Professional Geoscientist in Texas.

*** Jeffery D. King, P.G. received his Bachelor's Degree in Geology from Western Washington University and has over 25 years of technical and managerial experience in the natural-resource field. Mr. King has extensive management experience, has managed the operations of a mining company and large-scale redevelopment projects, and he has developed successful regulatory- and landowner-negotiation and public-relations programs. He also has conducted or directly managed many aspects of site permitting and financial and technical evaluations of mining properties for a major mining company. In the 1990s, Mr. King worked for the DuPont Company directing environmental projects in Washington, Oregon, Alaska and British Columbia, Canada. Over the years, he has founded three successful companies. The most recent is Pacific Environmental and Redevelopment Corporation, located in Seattle, Washington, to focus on large-scale projects involving the redevelopment of formerly environmentally challenged properties. He is licensed as a Professional Geologist in the State of Washington.