Commercialisation of a thorium fuelled pebble bed modular reactor

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Overview

- The importance of nuclear power in Africa
- Importance of correct energy utilization
- Proliferation Issues
- Thorium As A Nuclear Fuel Source
- The TH-100 Thorium Generator
- Summary
The importance of nuclear power in Africa

- Africa has a tremendous need for electrification in order to beneficiate its mineral resources as well as its human capital.
- History has shown that there is a direct relation between the GDP of a country and the amount of electricity generated in that country.
World energy consumption per capita 2003

Africa has the lowest consumption per capita in the world
GDP versus energy consumption
Switzerland

![Graph showing GDP versus energy consumption in Switzerland. The x-axis represents years from 1950 to 2010, and the y-axis shows total energy consumption per capita [GJ] and real GDP per capita [1,000 CHF]. The graph includes two lines: one for total energy (left scale) and one for real GDP (right scale).]
GDP versus energy consumption
Japan
Africa Does Have Diverse Energy Resources

Biomass

Wind

Nuclear

Geothermal

Coal

Natural Gas

Oil

We must decide how best to utilize them

Hydro

Solar

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Importance of correct energy utilization

- Oil, gas and coal are not renewable energy sources and pricing is volatile and inconsistent.
- Presently we don’t have alternative power sources for aircraft, ships and trucks.
- We are as dependent on transport as we are on electricity.
- We should therefore not be using precious resources such as oil, gas and even coal where we have an alternative solution such as nuclear.
Africa’s installed capacity
Top 18 countries

Total Electricity Installed Capacity (GW) in Africa

None of these countries can use large PWR reactors

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Transmission losses

Distribution losses in Africa


Data for countries in Africa from 2008 to 2010.

% losses:
- 0.00%
- 5.00%
- 10.00%
- 15.00%
- 20.00%
- 25.00%
- 30.00%

Countries included:
- Africa
- South Africa
- Egypt
- Algeria
- Libya
- Morocco
- Nigeria
- Tunisia
- Congo
- Mozambique
- Sudan
- Ethiopia
- Zimbabwe
- Ghana
- Kenya
- Zambia
- Ivory Coast
- Angola
- Cameroon

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Power Should Be Generated Where It Is Needed

The TH-100 is also the ideal plant to use in stabilizing electricity grids that rely on long distance transmission.

80% of the power is generated in the central part.

Electricity needs to be delivered by transmission lines for 1200km.
Using smaller distributed power plants in strategic areas reduces the demand on long distance grid and improves local grid stability while reducing transmission losses.
Africa Nuclear context

- South Africa is currently the only African country with nuclear power plants (the two unit Koeberg power station).
- Many other African countries have already made statements to the International Atomic Energy Agency in Vienna of their intention to introduce nuclear power for the first time.

The so-called "Newcomer countries"
So why only RSA? What are the barriers to entry?

- Many barriers have to be overcome when nuclear power plants are introduced the first time.
- Probably the most important is the large financial commitment needed for such a program.
- Proliferation issues.
- Need well established grid for traditional nuclear.
- South Africa is considering the introduction of 9600MWe over the next 20 years as announced in the Integrated Resource Plan.
  - “A potential nuclear fleet will involve a level of investment unprecedented in South Africa” ¹
Proliferation Issues

- One problem with traditional nuclear power programs is that they can be used as a gateway to producing weapons of mass destruction.
- The use of uranium means that plutonium is bead during the fuel cycle and a significant amount of plutonium is resident in the spent fuel.
- Thorium provides an alternative to uranium based fuels and does not produce plutonium in the spent fuel.
Some Facts About Thorium

- Thorium is a naturally occurring radioactive element found in the earth's crust.
- Thorium is often produced as part of the tailings in rare earth separation process.
- It is approximately 4-5 times more abundant than uranium.
- Thorium is not fissionable but is fertile.
- This means that thorium can be used as the source to produce fissionable fuel such as U$^{233}$.
- Thorium holds a much higher energy content per kg when compared to uranium.
Thorium Energy Content

- To run a 1,000 MW reactor for a year requires **one tonne** of nuclear material to be fissioned.
- To produce 1 ton of uranium fissionable material one needs to mine 250 tons of uranium due to the fact that only 0.7% of the uranium mined is fissionable material (i.e. U235 that is mixed with U238)
- One ton of **thorium** is therefore equal to **250 tons of uranium** needed to produce one 1,000 MW-year in the light water reactor.
- The 250 tons of uranium produces 35 tons of enriched uranium, which becomes the spent fuel volume. Of that 35 tons, 300 kg is plutonium.
SA has Thorium: Steenkampskraal Mine

By the end of 2014 we will be producing purified thorium at the rate of 500 tons per year from this one mine.
SA Has The Technology To Utilize This Thorium

\[ n + \ ^{232}\text{Th} \rightarrow \ ^{233}\text{Th} \xrightarrow{\beta} \ ^{233}\text{Pa} \xrightarrow{\beta} \ ^{233}\text{U} \]

Thorium

Ability to reprocess other nuclear waste

Fuel

Reprocess

Generator

Waste

Cleaner less problematic waste

Pebble bed meltdown proof reactor
The TH-100 Thorium Generator

- The TH-100 is a 100MW\textsubscript{th} helium cooled power plant that features a thorium based fuel cycle.
- The heat source is based on pebble bed technology which has a proven \textit{meltdown proof} core.
- Power conversion is via a proven helical coil steam generator.
- The TH-100 is a CO\textsubscript{2}-free nuclear thermal power source that can be utilised for power generation, process heat applications, water desalination and hydrogen production.
- Small size and modular construction result in relatively low cost.
100% Passive Reactor Safety

- Passive safety is achieved through:
  - Low power density (3.8MW/m$^3$).
  - Strong negative temperature coefficient means the reactor automatically shuts down in loss of coolant event.

- No fission product transport mechanism:
  - helium is inert and is not activated,
  - dust is periodically removed,
  - He is continually purified.

- No phase change and no pressure buildup as in LWR during loss of coolant accident.

- No possible buildup of explosive hydrogen mixtures.
Multiple Independent Fission Product Barriers

- Barriers:
  - Fuel kernels (silicon carbide)
  - Pressure vessel
  - Containment building
Fuel Manufacturing (at NECSA)
Electricity or Steam production

The nuclear island is similar for both plants

Process heat applications:
- Water desalination
- Hydrogen production
- Oil sands
- Industrial cogeneration etc.
TH-100 Power Plant

Meltdown proof pebble bed reactor
Capital costs for the 10\textsuperscript{th} TH-100 fall to $185m per plant
## Competitive Levelised Energy Cost

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Coal</td>
<td>85.50</td>
<td>94.80</td>
<td>110.80</td>
</tr>
<tr>
<td>Advanced Coal</td>
<td>100.70</td>
<td>109.40</td>
<td>122.10</td>
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<tr>
<td>Advanced Coal with CCS</td>
<td>126.30</td>
<td>136.20</td>
<td>154.50</td>
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<tr>
<td>Conventional Combined Cycle</td>
<td>60.00</td>
<td>66.10</td>
<td>74.10</td>
</tr>
<tr>
<td>Advanced Combined Cycle</td>
<td>56.90</td>
<td>63.10</td>
<td>70.50</td>
</tr>
<tr>
<td>Advanced CC with CCS</td>
<td>80.80</td>
<td>89.30</td>
<td>104.00</td>
</tr>
<tr>
<td>Conventional Combustion Turbine</td>
<td>99.20</td>
<td>124.50</td>
<td>144.20</td>
</tr>
<tr>
<td>Advanced Combustion Turbine</td>
<td>87.10</td>
<td>103.50</td>
<td>118.20</td>
</tr>
<tr>
<td>Advanced Nuclear</td>
<td>109.70</td>
<td>113.90</td>
<td>121.40</td>
</tr>
<tr>
<td>Wind</td>
<td>81.90</td>
<td>97.00</td>
<td>115.00</td>
</tr>
<tr>
<td>Wind - Offshore</td>
<td>186.70</td>
<td>243.20</td>
<td>349.40</td>
</tr>
<tr>
<td>Solar PV</td>
<td>158.70</td>
<td>210.70</td>
<td>323.90</td>
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<tr>
<td>Solar Thermal</td>
<td>191.70</td>
<td>311.80</td>
<td>641.60</td>
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<tr>
<td>Geothermal</td>
<td>91.80</td>
<td>101.70</td>
<td>115.70</td>
</tr>
<tr>
<td>Biomass</td>
<td>99.50</td>
<td>112.50</td>
<td>133.40</td>
</tr>
<tr>
<td>Hydro</td>
<td>58.50</td>
<td>86.40</td>
<td>121.40</td>
</tr>
<tr>
<td><strong>TH-100</strong></td>
<td><strong>69.30</strong></td>
<td><strong>83.45</strong></td>
<td><strong>97.60</strong></td>
</tr>
</tbody>
</table>

Reference is for US data from EIA

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Summary

- Nuclear power is important for Africa as it can help to preserve precious resources such as oil, gas and coal for unique uses.
- Small modular reactors are ideal for the small electricity grids found in Africa.
- Affordable overnight costs make nuclear power accessible to most countries in Africa.
- Small meltdown proof reactors with a thorium fuel cycle make nuclear in Africa safer and politically less problematic.
Questions

Thanks for listening!
## Thorium Resources

<table>
<thead>
<tr>
<th>Country</th>
<th>Tonnes</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>846,000</td>
<td>16</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>50,000</td>
<td>1</td>
</tr>
<tr>
<td>Other countries</td>
<td>413,000</td>
<td>8</td>
</tr>
<tr>
<td>World total</td>
<td>5,385,000</td>
<td></td>
</tr>
</tbody>
</table>

**Estimated world thorium resources**

There is no international or standard classification for thorium resources and identified Th resources do not have the same meaning in terms of classification as identified U resources. Thorium is not a primary exploration target and resources are estimated in relation to uranium and rare earths resources.