The IAEA uranium classification system

Hari Tulsidas
Nuclear fuel resources

- Nuclear growth projections
- Nuclear fuel cycle and its peculiarities
- Uranium resources, demand and production
- Alternatives?
- Aspects of IAEA classification scheme
- Long-term projections of fuel supply
- What next?
Nuclear Energy today

442 NPPs in operation with 375 GW(e)
## Growth forecast for 2030

<table>
<thead>
<tr>
<th>Year of the forecast</th>
<th>Forecast- Lower</th>
<th></th>
<th>Forecast-Higher</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GWe</td>
<td>Increase (%)</td>
<td>GWe</td>
<td>Increase (%)</td>
</tr>
<tr>
<td>IAEA 2003</td>
<td>386</td>
<td>1</td>
<td>573</td>
<td>1</td>
</tr>
<tr>
<td>IAEA 2004</td>
<td>423</td>
<td>+9.6</td>
<td>592</td>
<td>+3.3</td>
</tr>
<tr>
<td>IAEA 2005</td>
<td>418</td>
<td>+8.3</td>
<td>640</td>
<td>+11.7</td>
</tr>
<tr>
<td>IAEA 2006</td>
<td>414</td>
<td>+7.3</td>
<td>679</td>
<td>+18.5</td>
</tr>
<tr>
<td>IAEA 2007</td>
<td>447</td>
<td>+15.8</td>
<td>691</td>
<td>+20.6</td>
</tr>
<tr>
<td>IAEA 2008</td>
<td>473</td>
<td>+22.5</td>
<td>748</td>
<td>+30.5</td>
</tr>
<tr>
<td>IAEA 2009</td>
<td>511</td>
<td>+32.4</td>
<td>807</td>
<td>+40.8</td>
</tr>
</tbody>
</table>
Material flow in the fuel cycle

- **Natural Uranium**
  - conversion to **UF6**
  - enrichment to **Enriched UF6**

- **RU Storage**
  - Oxidation to **Recycled Reprocessed Uranium**

- **Optimized Geological Disposal**
  - Final Waste

- **Reprocessed Uranium**
  - Reprocessing

- **Used Fuel**
  - Fabrication to Fresh Fuel Assemblies or ENU

- **Plutonium**

- **NPPs**

- **TWh**
# World distribution of uranium resources

## Red Book 2009

<table>
<thead>
<tr>
<th>Country</th>
<th>tU</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1,679,000</td>
<td>26.6%</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>832,000</td>
<td>13.2%</td>
</tr>
<tr>
<td>Russia</td>
<td>565,000</td>
<td>9.0%</td>
</tr>
<tr>
<td>Canada</td>
<td>544,000</td>
<td>8.6%</td>
</tr>
<tr>
<td>United States</td>
<td>472,100</td>
<td>7.5%</td>
</tr>
<tr>
<td>South Africa</td>
<td>295,600</td>
<td>4.6%</td>
</tr>
<tr>
<td>Namibia</td>
<td>284,200</td>
<td>4.5%</td>
</tr>
<tr>
<td>Brazil</td>
<td>278,700</td>
<td>4.4%</td>
</tr>
<tr>
<td>Niger</td>
<td>275,500</td>
<td>4.3%</td>
</tr>
<tr>
<td>Others</td>
<td>1,079,000</td>
<td>17%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>6,306,000</td>
<td>100%</td>
</tr>
</tbody>
</table>

Undiscovered Resources: 10,400,000 tU

## iNFCIS - UDEPO

- Data of 1,352 uranium deposits from 75 countries
- Total 25,982,894 tU
- Recoverable Resources Identified: 9260 tU
- Total Resources Identified:

IAEA /OECD NEA Uranium 2009: Resources, Production and Demand

http://www-nfcis.iaea.org
Skewed Demand Versus Supply (1)
Skewed Demand Versus Supply (2)

> 600,000 tU
not used for fuel

* 2007 values are estimates.
Uranium production 2009

Total 50772 tU

(Required 68646 tU)
Thorium as fuel

- Large **resources** of thorium
- **Self sustained** equilibrium thorium fuel cycle
- Intrinsic **proliferation resistance**
- Better thermo-physical properties and **chemical stability**
- **High burn – up** capability
- Lesser long lived **minor actinides**
- Superior **plutonium incineration**
- Attractive in **accelerated driven systems** and energy amplifiers
Thorium Resources

Data based on Red Book 2009 & ThDEPO 2010
The ‘Red Book’

- Publisher jointly by OECD-NEA and IAEA
- Standard for making official country resource submissions.
- All countries are encouraged to openly report their uranium resources using a classification that is compatible with the national systems.
Aspects considered

- Consideration for recoverability
- Adjustment of estimate for past production
- Meaningful economic analysis of production cost
- Take into account all costs in economic analysis - such as infrastructure and rehabilitation following operation
- Avoid obsolete economic evaluation
## Flow of resources

<table>
<thead>
<tr>
<th>Economic</th>
<th>Identified resources that are currently economic mostly in operating mines</th>
<th>Undiscovered resources that –if found now- would likely be mineable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub economic</td>
<td>Identified resources that are not now mineable</td>
<td>Undiscovered resources that –if found now-would not now be mineable</td>
</tr>
</tbody>
</table>

- **Higher costs or Lower prices**
- **Mining & Processing**
## NEA-IAEA Classification Scheme (1)

<table>
<thead>
<tr>
<th>Recoverable at costs</th>
<th>IDENTIFIED RESOURCES</th>
<th>UNDISCOVERED RESOURCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>USD &lt;40/KgU</td>
<td>Reasonably Assured Resources</td>
<td>Inferred Resources</td>
</tr>
<tr>
<td>USD 40-80/KgU</td>
<td>Reasonably Assured Resources</td>
<td>Inferred Resources</td>
</tr>
<tr>
<td>USD 80-130/KgU</td>
<td>Reasonably Assured Resources</td>
<td>Inferred Resources</td>
</tr>
<tr>
<td>USD 130-260/KgU</td>
<td>Reasonably Assured Resources</td>
<td>Inferred Resources</td>
</tr>
</tbody>
</table>

- **Decreasing economic attractiveness**
- **Decreasing confidence in estimates**
NEA-IAEA Classification (2)

- Confidence level of the estimates
- Market based cost of producing (or recovering) the resource (ore concentrate – yellow cake).

**Identified resources**
- *Reasonably Assured Resources (RAR)* – estimates based on specific sample data and measurements - RECOVERABLE
- *Inferred Resources* – estimates based on direct geological evidence in the extensions of well-explored deposits; but specific data inadequate - RECOVERABLE

**Undiscovered Resources**
- *Prognosticated Resources* – estimates based on indirect evidence in well-defined geological trends or areas of mineralisation – IN SITU
- *Speculative Resources* – estimates based on indirect evidence and geological explorations – IN SITU
# NEA-IAEA classification (4)

<table>
<thead>
<tr>
<th>NEA/IAEA</th>
<th>Identified Resources</th>
<th>Undiscovered Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IAEA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Demonstrated</td>
<td>Inferred</td>
</tr>
<tr>
<td></td>
<td>Measured</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Indicated</td>
<td></td>
</tr>
<tr>
<td><strong>NEA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada (NRCan)</td>
<td>Measured</td>
<td>Inferred</td>
</tr>
<tr>
<td></td>
<td>Indicated</td>
<td></td>
</tr>
<tr>
<td><strong>DOE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>Reasonably Assured</td>
<td>Estimated Additional</td>
</tr>
<tr>
<td>(DOE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russian Federation, Kazakhstan,</td>
<td>A+B</td>
<td>C1</td>
</tr>
<tr>
<td>Ukraine, Uzbekistan</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNFC*</td>
<td>G1+G2</td>
<td>G3</td>
</tr>
</tbody>
</table>

* UNFC correlation with NEA/IAEA and national classification systems is still under consideration
Recoverable resources

- Mining and ore processing losses are deducted

<table>
<thead>
<tr>
<th>Method</th>
<th>Overall recovery factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open pit</td>
<td>80</td>
</tr>
<tr>
<td>Underground</td>
<td>75</td>
</tr>
<tr>
<td>ISL (acid)</td>
<td>75</td>
</tr>
<tr>
<td>ISL (alkaline)</td>
<td>70</td>
</tr>
<tr>
<td>Heap Leach</td>
<td>70</td>
</tr>
<tr>
<td>Block / Stope Leach</td>
<td>70</td>
</tr>
<tr>
<td>Co/Bi product</td>
<td>75</td>
</tr>
<tr>
<td>Unspecified</td>
<td>75</td>
</tr>
</tbody>
</table>
Resource versus requirements

- Higher cost RAR & Inferred
- Low cost Inferred
- Low cost RAR

Cumulative requirements

Total quantity of Uranium

- Today
- 10 years
- 20 years
- 30 years
- 40 years
Demand projections

High case

Uranium cumulative demand (BAU-plus High case)

- Total
- ultimate resource ~ additional 16 million ton
- known resource ~ additional 5 million ton

37.8 Mton at 2100

Moderate case

Uranium cumulative demand (BAU-plus Moderate case)

- Total
- ultimate resource ~ additional 16 million ton
- known resource ~ additional 5 million ton

22.6 Mton at 2100

IAEA-INPRO Study 2010
Life index and its limitations

Life Index = 10

Modified Life Index = 6.3

Likely Depletion Pattern (3 years of production at adequate levels)
Deposit by deposit analysis

World RAR <260$ (80% minecapacity)

IAEA

N Arnold, Univ of Natural Resources, Vienna
Projected supply

I Reliable Supply (Production facilities in place)
II Likely Supply
III Uncertain Supply
Production terminology

- **Production centres** - a production unit consisting of one or more ore processing plants, one or more associated mines and uranium resources that are tributary to these facilities.
  - **Existing** production centres are those that currently exist in operational condition and include those plants which are closed down but which could be readily brought back into operation.
  - **Committed** production centres are those that are either under construction or are firmly committed for construction.
  - **Planned** production centres are those for which feasibility studies are either completed or under way, but for which construction commitments have not yet been made. This class also includes those plants that are closed which would require substantial expenditures to bring them back into operation.
  - **Prospective** production centres are those that could be supported by tributary RAR and Inferred, i.e., “Identified Resources”, but for which construction plans have not yet been made.
Supply from production centres (1)
Supply from production centres (2)
Supply from production centres (3)
Production by cost category
Planned activities

- **2011**
  - Technical Meeting on World Thorium Resources, 17-21 October 2011, India.
  - Technical meeting on Good practices in production of uranium from phosphoric acid, November 2011, Vienna, Austria
- **2012**
  - Technical Cooperation Inter-regional project on Uranium production - Regional workshops, training programmes, fellowships etc.
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