URANIUM

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Nuclear Fuel Cycle (NFC)

- Nuclear fuel cycle is the series of industrial processes which involve the production of electricity from uranium in nuclear power reactors.
NUCLEAR FUEL CYCLE (NFC)

1. Natural Uranium & Thorium
2. Milling
3. Conversion
4. Enrichment
5. Fuel Fabrication
6. Secondary Supply
7. Power Plant
8. Spent Fuel Storage
9. Reprocessing
10. HLW

- 230 t U3O8 (195 t U)
- 288 t UF6 (195 t U; 0.7% U-235)
- 20,000 t U-ore, (1%)
- 35 t e-UF6 (24 t e-U; 3-5% U-235)
- 27 t U3O8 (195 t U)
- 27 t reprocessing
- 27 t UO2 (24 t eU; 3-5% U-235)
- 8760 GWh p.a. (1000MW 100%)

Electricity

Resource Demand Supply

In/near reactor

Or directly to disposal

Secondary Supply

Natural Uranium & Thorium
1. Mining

This process produces: **Uranium Ore**
a sufficiently high concentration of uranium in the ground that extraction of it for use as nuclear fuel is economically feasible.

Original ore may contain as little as 0.1% uranium, or less.

Techniques to recover uranium ore:
- excavation and
- in situ leaching (ISL).
Chemical solution is circulated through a very porous ore body to dissolve the uranium oxide and bring it to the surface.

When ore body contains high level of:
calcium $\rightarrow$ NaHCO3 + CO2 solution (base)  
Otherwise $\rightarrow$ H2SO4 + O2 (acid)  
The uranium oxide is then recovered from the solution as in a conventional mill.

Excavation:
- **open pit mining**  
  (if deposits are close to surface) and  
- **Underground**  
  (if deposits $>$ 120 m).
In Situ Leaching
Uranium occurs in two valence states, $U^{4+}$ and $U^{6+}$.

$U^{6+}$ {in which state it forms the uranyl ion $(UO_2)^{2+}$ } soluble in groundwater, whereas $U^{4+}$ compounds are not.

So long as the groundwater remains oxidizing, uranyl ions are stable and uranium can be transported by groundwater; however, when uranyl ions encounter a reducing agent such as organic matter, $U^{4+}$ uranium is precipitated as uraninite and coffinite.

Because groundwater flowing through an aquifer and meeting a reducing zone will deposit a zone, or front, of uraninite.
Uranium Characteristics (2/2)

- **Density**: 19.1 gr/cc --- although very dense, is a relatively weak, nonrefractory metal

- Indeed, the metallic properties of uranium appear to be intermediate between those of silver and other true metals and those of the nonmetallic elements, so that it is not valued for structural applications

- The principal value of uranium is in the radioactive and fissionable properties of its isotopes. In nature, almost all (99.27 percent) of the metal consists of uranium-238; the remainder consists of uranium-235 (0.72 percent) and uranium-234 (0.006 percent).
Uranium occurs in a number of different igneous, hydrothermal and sedimentary geological environments. Most of Australia's uranium resources are in two kinds of orebodies, unconformity-related and breccia complex, while sedimentary deposits are less significant than overseas. Most Canadian deposits are unconformity-related
Geology of Uranium Deposits (2/3)

Major categories of deposit types based on the geological setting of the deposits

- **Unconformity-related deposits**
  - 33% of the western world's uranium resources
  - The main deposits occur in **Canada** (the Athabasca Basin, Saskatchewan and Thelon Basin, Northwest Territories); and **Australia** (the Alligator Rivers region in the Pine Creek Geosyncline, NT and Rudall River area, WA)

- **Hematite breccia complex deposits**
Sandstone deposits
- 18% of world uranium resources and are of major economic importance in Kazakhstan

Quartz-pebble conglomerate deposits
- 13% of the world's uranium resources

Surficial deposits
- 4% of world uranium resources
2. Milling

Milling extracts the uranium from the ore.

This process produces: Uranium oxide U3O8 concentrate (yellow cake).

Yellowcake generally contains >80% uranium.

Technique:
Uranium is extracted from the crushed and ground-up ore by leaching (a strong acid or a strong alkaline solution is used to dissolve the uranium oxide) → The uranium oxide is then precipitated and removed from the solution → After drying and usually heating it is packed in 200-litre drums as a concentrate.
Tailing:

- The remainder of the ore, nearly all the rock material
- Contain long-lived radioactive materials in low concentrations and toxic materials such as heavy metals; however, the total quantity of radioactive elements is less than in the original ore, and their collective radioactivity will be much shorter-lived.
Open pit mining → Crushing & grinding → Leaching → Separate solids → Extract U in liquor → Precipitate uranium → Separate solids → Drying → Uranium oxide concentrate, \( \text{U}_3\text{O}_8 \) (yellowcake) contains approximately 85% by weight of uranium
3. Conversion

The conversion process produces:

a. Uranium dioxide (UO2), solid, direct use for PHWR or

b. Uranium hexafluoride (UF6), gaseous

At a conversion facility:

a. Yellowcake (U3O8) is first refined to uranium dioxide (UO2) → fuel for types of reactors that do not require enriched uranium (PHWR).

b. Or it is then converted into uranium hexafluoride (UF6) ready for the enrichment plant. The uranium hexafluoride is then drained into 14-tonne cylinders where it solidifies → shipped to the enrichment plant.
4. Enrichment

This process produces: **Enriched uranium dioxide (UO2), solid**

Only 0.7% of natural uranium is 'fissile' (isotope U-235), the remainder 99.3% is uranium-238 (U-238).

For most kinds of reactor, the **concentration** of the fissile uranium-235 isotope needs to be increased – typically to between **3% and 5%** U-235. This is done by a process known as enrichment, which requires the uranium to be in a gaseous form.
Techniques:

- diffusion or
- centrifuge

Unenriched UF6 (gas) $\rightarrow$ enriched UF6 $\rightarrow$ reconverted to enriched UO2
To reduce U238:
- The idea is to separate isotope U-235 from U-238, using the physical properties of molecules, specifically the 1% mass difference between the two uranium isotopes then reduce the U-238.
- U3O8 may contain both isotope → one cannot be separated from another.
- U3O8 must be converted to UF6 (gas), because when in a single U compound and gaseous, it’s possible for mass separation.
- Centrifuged or diffused → heavier isotope (U238) stays separately → cut down
The centrifuge process uses UF6 gas as its feed and makes use of the slight difference in mass between U-235 and U-238. The gas is fed into a series of vacuum tubes, each containing a rotor 3 to 5 metres tall and 20 cm diameter. To obtain efficient separation of the two isotopes, centrifuges rotate at very high speeds (50,000-70,000 rpm), giving the outer wall of the spinning cylinder moving at between 400 and 500 metres per second to give a million times the acceleration of gravity.

The heavier molecules with U-238 increase in concentration towards the cylinder’s outer edge. There is a corresponding increase in concentration of U-235 molecules near the centre. The countercurrent flow set up by a thermal gradient enables enriched product to be drawn off axially, heavier molecules at one end and lighter ones at the other.

The enriched gas forms part of the feed for the next stages while the depleted UF6 gas goes back to the previous stage.
The graph shows how one tonne of natural uranium feed might end up: as 120-130 kg of uranium for power reactor fuel, as 26 kg of typical research reactor fuel, or conceivably as 5.6 kg of weapons-grade material. The curve flattens out so much because the mass of material being enriched progressively diminishes to these amounts, from the original one tonne, so requires less effort to progress. The relatively small increment of effort needed to achieve the increase from normal levels is the reason why enrichment plants are considered a sensitive technology in relation to preventing weapons proliferation, and are very tightly supervised under international agreements.
Burn Up is a measure of heat contained within 1 tonne of nuclear fuel. In coal, it is the heat value (kcal/kg).

Measured in GWd/tonne and its potential is proportional to the level of enrichment.

- 45 GWd/ton ~ 4% → most reactors (18 months).
- 55 GWd/ton ~ 5.5% → possible.
- 70 GWd/ton ~ 6% → insight.
  - Longer operation cycle (24 months).
  - Reduce number of spent fuel (from 1/3 part to ~1/5 part) → Associated fuel cycle cost is reduced by 20%.
5. Fuel Fabrication

This process produces: **Fuel assembly**

Reactor fuel is generally in the form of ceramic pellets

**Technique:**
- Uranium oxide (UO2) is pressed to pellet shape and sintered (baked) at a high temperature (over 1400°C)
- Pellets are then encased in metal tubes to form fuel rods.
- Fuel rods are arranged into a fuel assembly ready for introduction into a reactor.

The dimensions of the fuel pellets and other components of the fuel assembly are precisely controlled **to ensure consistency in the characteristics of the**
The cost of 1 kg nuclear fuel

In January 2010, the approx. US $ cost to get 1 kg of uranium as UO2 reactor fuel (at likely contract price for the natural uranium from a mine):

<table>
<thead>
<tr>
<th></th>
<th>Uranium: $115.50 kg U₃O₈</th>
<th>Conversion: $12 kg U</th>
<th>Enrichment: $164 SWU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium</td>
<td>8.9 kg U₃O₈ x $115.50</td>
<td>7.5 kg U x $12</td>
<td>7.3 SWU x $164</td>
</tr>
<tr>
<td>Total, approx.</td>
<td>US$ 1028</td>
<td>US$ 90</td>
<td>US$ 1197</td>
</tr>
</tbody>
</table>

Fuel fabrication: per kg UO2 US$ 240

Total, approx: US$ 2555

At 45 GWd/t burn-up (equals to 4% enrichment) this gives 360,000 kWh electrical per kg, hence fuel cost: **0.71 c/kWh**
6. Secondary supplies for fuel

Primary Sources:
- Natural uranium (Unat) extracted from ore deposits

Secondary Sources:
- Stock holdings of natural uranium and Low Enriched Uranium (LEU)
- Uranium re-enriched from depleted uranium,
- Uranium recycled from spent fuel,
- Plutonium recycled from spent fuel, or surplus nuclear weapons, for use in MOX fuel, and
- Uranium blended down from High Enriched Uranium (HEU).
1959

Military stockpiles build-up

1981
Commercial stockpiles build-up

1993

Secondary supplies

Primary supplies (mine production)

Megatons to Megawatts programme

+ 2007 values are estimates.

World Requirements

World Production
URANIUM BLENDED DOWN

MEGATON – MEGAWATT PROGRAM
1993

RUSIA
500 T HEU recycled into LEU
is scheduled to be completed in 2013

USA
150 T HEU recycled into LEU
is scheduled to be completed in 2013

1994
Addition of 250 tonne HEU
In market until 2023/2040

1994
Addition of 55 tonne HEU
In market until 2023/2040
7. Electricity Generation

1 year operation (360 days) at full power of a 1000 MW NPP produces 8640 million kWh

The operation requires 27 tonnes of nuclear fuel (~135,000 UO2 pellets), containing ~24 tonnes of enriched U

This pellet provides us with Over 6400 kWh of electricity. This will power up a house of 1000 W for a year*

*17 hours full power per day

Nuclear:Coal fuel mass requirements = 1 : 150,000
8. Spent Fuel

Spent fuel illustration based on 3% enrichment

- 3% U-235
- 97% U-238
- 95% U-238
- 1% Pu
- 1% U-235 left
- 3% fission product

Fresh fuel | Spent Fuel
---|---

Reusable Material → waste
Spent fuel may be treated as a resource or simply as a waste.

Before further treatment spent fuel is first stored at the cooling pond.

- When removed from a reactor, the fuel will be emitting both radiation, principally from the fission fragments, and heat. Spent fuel is unloaded into a storage pond immediately adjacent to the reactor to allow the radiation levels to decrease and the temperature to cool down. In the pond the water shields the radiation and absorbs the heat. Spent fuel is held in such pools for several months to several years.

- So after 12-24 months spent fuel is removed from the reactor for reprocessing.
9. Reprocessing

- **In a reprocessing facility the spent fuel is separated into its three components: uranium, plutonium and waste** (which contains fission products).
- **Reprocessing enables recycling** of the uranium and plutonium into fresh fuel, and produces a significantly reduced amount of waste (compared with treating all spent fuel as waste).
- The uranium from reprocessing, which typically contains a slightly higher concentration of U-235 than occurs in nature, can be reused as fuel after conversion and enrichment.
- The plutonium can be directly made into mixed oxide (MOX) fuel, in which uranium and plutonium oxides are combined. In reactors that use MOX fuel, plutonium substitutes for the U-235 in normal uranium oxide fuel.
10. Waste Disposal

- **The radioactivity of all nuclear waste decays with time.** Each radionuclide contained in the waste has a half-life – the time taken for half of its atoms to decay and thus for it to lose half of its radioactivity. Radionuclides with long half-lives tend to be alpha and beta emitters – making their handling easier – while those with short half-lives tend to emit the more penetrating gamma rays. Eventually all radioactive wastes decay into non-radioactive elements. *The more radioactive an isotope is, the faster it decays.*

- The amount of radioactive wastes is **very small relative to** wastes produced by fossil fuel electricity generation.

- Nuclear power is the only large-scale energy-producing technology which **takes full responsibility for all its wastes and internalised the costs** this into the product.

- Safe methods for the final disposal of high-level radioactive waste are technically proven; the **international consensus** is that this should be **deep geological disposal.**

- At each stage of the fuel cycle there are proven technologies to dispose of the radioactive wastes safely. For **low- and intermediate-level wastes** these are mostly being implemented. For high-level wastes some countries await the accumulation of enough of it to warrant building geological repositories; others, such as the USA, have encountered political delays.
### NPP RADIOACTIVE WASTE

#### 1000 MWe/YEARS (PWR)

#### HIGH LEVEL WASTE

**Volume:** 8 m³

- Am (t½) 432 y
- Tc (t½) 210 y
- Pu (t½) 24.4 y

#### LOW-MEDIUM LEVEL WASTE

**Volume:** 300 m³

- Xe (t½) 5.3 days
- I-131 (t½) 8 days
- Co-60 (t½) 5.27 y
- Sr-90 (t½) 27.7 y
- Cs-137 (t½) 30 y
NPP Low-Medium Level Waste Handling
NPP High Level Waste Handling

• At present time, there are no disposal facilities in operation, because:
  
   **surface storage for 40-50 years is first required** so that heat and radioactivity can decay to levels which make handling and storage easier.
  
   there is currently no pressing need to establish such facilities, as the total volume of such wastes is relatively small.
  
   the longer it is stored the easier it is to handle, due to the progressive diminution of radioactivity.
  
   There is also a reluctance to dispose of spent fuel because it represents a significant energy resource which could be reprocessed at a later date to allow recycling of the uranium and plutonium.
  
   There is also a proposal to use it in Candu reactors directly as fuel. This proposal is known as DUPIC (direct use of used PWR fuel in Candu reactors)
### Waste management for spent fuel and HLW from nuclear power reactors

<table>
<thead>
<tr>
<th>Country</th>
<th>Policy</th>
<th>Facilities and progress towards final repositories</th>
</tr>
</thead>
</table>
| Belgium  | Reprocessing | Central waste storage at Dessel  
  - Underground laboratory established 1984 at Mol  
  - Construction of repository to begin about 2035                                                             |
| Canada   | Direct disposal | Nuclear Waste Management Organisation set up 2002  
  - Deep geological repository confirmed as policy, retrievable  
  - Repository site search from 2009, planned for use 2025                                                        |
| China    | Reprocessing | Central spent fuel storage at LanZhou  
  - Repository site selection to be completed by 2020  
  - Underground research laboratory from 2020, disposal from 2050                                                  |
| Finland  | Direct disposal | Program start 1983, two spent fuel storages in operation  
  - Posiva Oy set up 1995 to implement deep geological disposal  
  - Underground research laboratory Onkalo under construction  
  - Repository planned from this, near Olkiluoto, open in 2020                                                      |
<table>
<thead>
<tr>
<th>Country</th>
<th>Method</th>
<th>Details</th>
</tr>
</thead>
</table>
| France    | Reprocessing         | Underground rock laboratories in clay and granite  
  • Parliamentary confirmation in 2006 of deep geological disposal, containers to be retrievable and policy "reversible"  
  • Bure clay deposit is likely repository site to be licensed 2015, operating 2025 |
| Germany   | Reprocessing but moving to direct disposal | Repository planning started 1973  
  • spent fuel storage at Ahaus and Gorleben salt dome  
  • Geological repository may be operational at Gorleben after 2025 |
| India     | Reprocessing         | • Research on deep geological disposal for HLW                                                                                       |
| Japan     | Reprocessing         | Underground laboratory at Mizunami in granite since 1996  
  • High-level waste storage facility at Rokkasho since 1995  
  • High-level waste storage approved for Mutsu from 2010  
  • NUMO set up 2000, site selection for deep geological repository under way to 2025, operation from 2035, retrievable |
| Russia    | Reprocessing         | Underground laboratory in granite or gneiss in Krasnoyarsk region from 2015, may evolve into repository  
  • Sites for final repository under investigation on Kola peninsula  
  • Various interim storage facilities in operation |
| South Korea | Direct disposal | Waste program confirmed 1998  
  • Central interim storage planned from 2016 |
<table>
<thead>
<tr>
<th>Country</th>
<th>Approach</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>Direct disposal</td>
<td>ENRESA established 1984, its plan accepted 1999</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Central interim storage probably at Trillo from 2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Research on deep geological disposal, decision after 2010</td>
</tr>
<tr>
<td>Sweden</td>
<td>Direct disposal</td>
<td>Central spent fuel storage facility – CLAB – in operation since 1985</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Underground research laboratory at Aspo for HLW repository</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Osthammar site selected for repository (volunteered location)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Reprocessing</td>
<td>Central interim storage for HLW at Zwilag since 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Central low &amp; ILW storages operating since 1993</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Underground research laboratory for high-level waste repository at</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grimsel since 1983</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Deep repository by 2020, containers to be retrievable</td>
</tr>
<tr>
<td>United</td>
<td>Reprocessing</td>
<td>Low-level waste repository in operation since 1959</td>
</tr>
<tr>
<td>Kingdom</td>
<td></td>
<td>• HLW from reprocessing is vitrified and stored at Sellafield</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Repository location to be on basis of community agreement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• New NDA subsidiary to progress geological disposal</td>
</tr>
<tr>
<td>USA</td>
<td>Direct disposal but</td>
<td>DoE responsible for spent fuel from 1998, $32 billion waste fund</td>
</tr>
<tr>
<td></td>
<td>reconsidering</td>
<td>• Considerable research and development on repository in welded tuffs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>at Yucca Mountain, Nevada</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 2002 decision that geological repository be at Yucca Mountain was</td>
</tr>
<tr>
<td></td>
<td></td>
<td>countered politically in 2009</td>
</tr>
</tbody>
</table>
Proposed plan for deep geological formation repository in Sweden

The Swedish concept for the disposal of spent nuclear fuel as an illustration of the multi-barrier concept.

30. Spent fuel will be encapsulated in a copper canister with an iron insert. The iron insert provides mechanical stability and the copper shell corrosion protection. Each canister is about 4.8 m long, has a diameter of 1 m, and weighs around 25 tonnes. The canisters will be disposed of in tunnels (KBS-3H) or deposition holes (KBS-3V) at a depth of 400–700 m in crystalline bedrock. The void between the bedrock and the canisters will be filled with compacted bentonite clay (Figure 5).
URANIUM
RESOURCES, PRODUCTION, DEMAND
DISTRIBUTION OF IDENTIFIED URANIUM RESOURCES

(Red Book 2007)
<table>
<thead>
<tr>
<th></th>
<th>&lt; US $ 40 / kgU</th>
<th>&lt; US $ 80 / kgU</th>
<th>&lt; US $ 130 / kgU</th>
</tr>
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<tbody>
<tr>
<td>World</td>
<td>~ 3,000</td>
<td>~ 4,500</td>
<td>~ 5,500</td>
</tr>
<tr>
<td>Australia</td>
<td>1,196</td>
<td>1,216</td>
<td>1,243</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>517</td>
<td>752</td>
<td>817</td>
</tr>
<tr>
<td>Russia</td>
<td>84</td>
<td>495</td>
<td>546</td>
</tr>
<tr>
<td>South Africa</td>
<td>235</td>
<td>343</td>
<td>423</td>
</tr>
<tr>
<td>Canada</td>
<td>352</td>
<td>423</td>
<td>435</td>
</tr>
<tr>
<td>USA</td>
<td>NA</td>
<td>99</td>
<td>&gt;&gt; 339</td>
</tr>
<tr>
<td>Brazil</td>
<td>140</td>
<td>231</td>
<td>278</td>
</tr>
<tr>
<td>Namibia</td>
<td>116</td>
<td>230</td>
<td>275</td>
</tr>
<tr>
<td>Niger</td>
<td>34</td>
<td>75</td>
<td>274</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>86</td>
<td>86</td>
<td>111</td>
</tr>
</tbody>
</table>

Identified (Reasonably Assured + Inferred) Resources (in 1000 tonnes)
## URANIUM RESOURCES BY DEPOSIT TYPE

(Reasonably Assured Resources)

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>&lt;USD 40/kgU</th>
<th>&lt;USD 80/kgU</th>
<th>&lt;USD 130/kgU</th>
<th>&lt;USD 260/kgU</th>
</tr>
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<tbody>
<tr>
<td>Unconformity-related</td>
<td>267 078</td>
<td>536 815</td>
<td>559 416</td>
<td>564 301</td>
</tr>
<tr>
<td>Sandstone</td>
<td>32 875</td>
<td>424 208</td>
<td>888 529</td>
<td>1 118 830</td>
</tr>
<tr>
<td>Hematite breccia complex</td>
<td>0</td>
<td>900 300</td>
<td>908 000</td>
<td>908 000</td>
</tr>
<tr>
<td>Quartz-pebble conglomerate</td>
<td>61 085</td>
<td>82 147</td>
<td>108 822</td>
<td>108 822</td>
</tr>
<tr>
<td>Vein</td>
<td>0</td>
<td>7 432</td>
<td>64 611</td>
<td>129 048</td>
</tr>
<tr>
<td>Intrusive</td>
<td>1 013</td>
<td>4 997</td>
<td>97 091</td>
<td>100 093</td>
</tr>
<tr>
<td>Volcanic and caldera-related</td>
<td>0</td>
<td>132 410</td>
<td>166 813</td>
<td>193 480</td>
</tr>
<tr>
<td>Metasomatite</td>
<td>88 788</td>
<td>147 576</td>
<td>246 738</td>
<td>314 311</td>
</tr>
<tr>
<td>Other *</td>
<td>53 600</td>
<td>138 600</td>
<td>263 025</td>
<td>278 208</td>
</tr>
<tr>
<td>Unspecified</td>
<td>65 422</td>
<td>141 699</td>
<td>221 822</td>
<td>289 383</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>569 861</strong></td>
<td><strong>2 516 154</strong></td>
<td><strong>3 524 867</strong></td>
<td><strong>4 004 476</strong></td>
</tr>
</tbody>
</table>
World Uranium Production

- 2009: ~ 50,000 tonnes U
- 2008: 43,750 tonnes U
- 2007: 42,463 tonnes U
- 2006: 39,603 tonnes U
- 2005: 41,943 tonnes U
- 2004: 40,188 tonnes U
# World Uranium Production (2009)

<table>
<thead>
<tr>
<th>Location</th>
<th>2009 (rounded)</th>
<th>% share</th>
</tr>
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<tbody>
<tr>
<td>Kazakhstan</td>
<td>14 000</td>
<td>28</td>
</tr>
<tr>
<td>Canada</td>
<td>10 000</td>
<td>20</td>
</tr>
<tr>
<td>Australia</td>
<td>8 000</td>
<td>16</td>
</tr>
<tr>
<td>Namibia</td>
<td>4 600</td>
<td>9</td>
</tr>
<tr>
<td>Russia</td>
<td>3 600</td>
<td>7</td>
</tr>
<tr>
<td>Niger</td>
<td>3 200</td>
<td>6</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>2 500</td>
<td>5</td>
</tr>
</tbody>
</table>
World Uranium Production
### Expansion of Uranium Production

<table>
<thead>
<tr>
<th>Year</th>
<th>Country</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td><strong>Australia</strong> (Ranger Construction of laterite treatment plant to produce an additional 400 tU/yr)</td>
<td></td>
</tr>
</tbody>
</table>
| 2009 | **Niger** (Expansion of Somair & Cominak production capability by 700 tU/yr to a total of 4 500 tU/yr)  
**Kazakhstan** (Southern Zarechnoye 1000 tU/yr) |
| 2010 | **Canada** (Mc. Arthur River & Key Lake expansion to produce 8 800 tU/yr)  
**Brazil** (caetite expansion to 670 tU/yr)  
**Namibia** (langer Heinrich expansion to 2 000 tU/yr) |
| 2012 | **Namibia** (Rossing Expansion 4 500 tU/yr) |
| 2013 | **Australia** (Proposed Olympic Dam Expansion, to produce as much as 16 100 tU/yr) |
Uranium Production & Demand
Uranium Production & Demand

2007 production ~42 500 tU (62% demand) 2007 demand 69 100 tU
The GAP (>25 000 tU)
Is supplied from the so called “secondary supplies”

<table>
<thead>
<tr>
<th>Country</th>
<th>2007</th>
<th>% share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>9 500</td>
<td>22.3</td>
</tr>
<tr>
<td>Australia</td>
<td>8 600</td>
<td>20.2</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>6 600</td>
<td>15.5</td>
</tr>
<tr>
<td>Russia</td>
<td>3 400</td>
<td>8.0</td>
</tr>
<tr>
<td>Niger</td>
<td>3 200</td>
<td>7.4</td>
</tr>
<tr>
<td>Namibia</td>
<td>2 900</td>
<td>6.8</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>2 300</td>
<td>5.2</td>
</tr>
<tr>
<td>USA</td>
<td>1 700</td>
<td>4.0</td>
</tr>
<tr>
<td>Ukraine</td>
<td>1 000</td>
<td>2.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>2007</th>
<th>% share</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>22 825</td>
<td>33.0</td>
</tr>
<tr>
<td>France</td>
<td>9 000</td>
<td>13.0</td>
</tr>
<tr>
<td>Japan</td>
<td>8 790</td>
<td>12.7</td>
</tr>
<tr>
<td>Russia</td>
<td>4 100</td>
<td>5.9</td>
</tr>
<tr>
<td>Germany</td>
<td>3 490</td>
<td>5.1</td>
</tr>
<tr>
<td>South Korea</td>
<td>3 200</td>
<td>4.6</td>
</tr>
<tr>
<td>Ukraine</td>
<td>2 480</td>
<td>3.6</td>
</tr>
<tr>
<td>Canada</td>
<td>1 900</td>
<td>2.7</td>
</tr>
<tr>
<td>UK</td>
<td>1 900</td>
<td>2.7</td>
</tr>
</tbody>
</table>
URANIUM SPOT PRICES

Production Problem
Cyclone, water buildup, wellfiled slowdown, lower ore grade

Cigar lake flood

Production shortfalls
UF6 Prices
SEPARATIVE WORK UNIT

The diagram shows the trend of the Ux SWU Price from 1995 to 2010. The price has generally increased over the years, with some fluctuations.
Uranium and Thorium Deposit in Indonesia

- A 59.200 ton of $\text{U}_3\text{O}_8$ resource from several categories (hypothetical to indicated) is in Kalimantan Barat dan Kalimantan Timur.
- The known uranium deposit in Kalimantan Barat is 3.800 tonnes $\text{U}_3\text{O}_8$.
- Assumed that the total resource and deposit is economic for mining, Indonesia’s uranium will supply a 1000 MW NPP for ±300 years.
- The largest uranium resource is in Papua, nevertheless it has never been explored.
- A thorium resource (Hypothetical) of 121,500 tonnes, is in Kep. Bangka Belitung Province.
RADIOACTIVE MINERAL RESOURCES MAP (2010)

LEGEND
- Yellow: Speculative Resources Area of U
- Green: Indicated Resources Area of U
- Red: Potential Resources Area of U
- Brown: Potential Resources Area of Th

19. Maros Gowa 20. Banggai Sula
BUSSINES OPPORTUNITY
CURRENT SITUATION IN INDONESIA

- The existing map of radioactive mineral resources is still qualitative, to quantify it, the huge fund is needed.

- Available budget for financing exploration is very limited.
RELATED REGULATIONS:

- Act No. 10/1997 on Nuclear Energy
- President Decree No. 103/2001 jo. President Regulation No. 64/2005 on Non Department Government Agency (LPND)
- Act No. No. 4 year 2009 on Mineral and Coal Mining

Task, Function and Authority of BATAN among others:

conducting general survey, exploration, exploitation of nuclear ore and production of yellow cake

Inventory of the U potentials in Indonesia
Mastering the technology on yellow cake production
<table>
<thead>
<tr>
<th>MANDATE of Act no. 10/1997</th>
<th>PROBLEMS &amp; SOLUTIONS</th>
<th>THE EXISTING POLICY ELEMENTS</th>
</tr>
</thead>
</table>
| **ARTICLE 9** (1) General surveys, explorations and exploitations of nuclear material/ore only be implemented by the Executing Body. | • Required huge fund  
• BATAN is the only executor  
• The funding ability of BATAN is limited | • New and renewable energy source (including nuclear) will contribute to achieve 5% of the total of national primary energy as written in the Aim of National Energy Policy - 2025 (Govt Reg no 5 year 2006) |
| **ARTICLE 9** (2) The Executing Body under paragraph (1) may cooperate with any State Company, Cooperatives, Private Company, and/or other bodies. | Seek the investor which is interested on cooperation:  
- invent of U potentials  
- mastering the technology on yellow cake production |  |
| **ARTICLE 10** (1) The production and/or procurement of raw material for manufacturing nuclear fuel shall only be accomplished by the Executing Body | Required huge fund for U mining and yellow cake production | • Requirement of national nuclear fuel, mainly will be fulfilled by import, since the domestic uranium resources will only be used for the certain necessity.  
• Inventory of the national of U resources has to be continued.  |
| **ARTICLE 10** (2) The Executing Body under paragraph (1) may cooperate with any State Company, Cooperatives, and/or any private company | Seek the investor which is interested on cooperation of U mining and yellow cake production |  |
Inventory of U potentials will be conducted through cooperation with investor which is willing to fund the activity.

Condition of cooperation

Part of the discovered deposit from cooperation activity will be kept as in-situ reserve while the remaining deposit will be exploited for reimbursing the investor expenditures in accordance with the prevailing regulations.
DRAFT SCHEME OF PROFIT SHARING

**Gross Sales**

- **Exploitation Fee 2% of gross sale**
- **Landrent**

**Investor**

- **Cost Recovery of Exploration and Exploitation *)**

**Gov.**

- **15%**

**Profit**

- **1% of (profit-15%)**

**Community Development**

**Gov.**

- **Sale of Product of U Mining*)**

**Investor**

Note:

- Subtraction

*) Cost recovery shall be less than 80% of Gross Sales

Gov. : Government
USULAN Wilayah Usaha Pertambangan (WUP)
Terimakasih