l’avenir pour énergie
AVAILABILITY OF RESOURCES - CONSIDERATIONS on FUEL CYCLE and OBJECTIVES for LOCALIZATION

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- A Brief on Fuel cycle
- Context, obligations, possibilities potential interest of localization
- Feedback on Fuel Cycle market and waste management
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- Context, obligations, possibilities potential interest of localization

- Feedback on Fuel Cycle market and waste management
Fuel cycle: supply of products & services at front end and back end of nuclear reactor

- **Front End**
  - Natural Uranium
  - Conversion
  - Enrichment

- **Back End**
  - Ultimate Waste management
  - Recycling of spent fuel

- **Product**
  - Service
  - Product

**Key Symbols**
- \( \text{U}_3\text{O}_8 \)
- \( \text{UF}_6 \)
- \( \text{DUF}_6 \)
- \( \text{PuO}_2 \)
- MOX

- **Depleted** \( \text{UF}_6 \) (DUF)
Nuclear Fuel: A sophisticated product with high added value

Key functions
- Heat Production and transfer towards coolant
- First containment barrier

High technology
- 1 type of product for 1 type of reactor
- Typical ‘Time to market’ for a new product is 10 et 15 ans

Increasingly high expectations and requirements
- Clients require 0 problems - 0 defects to their fuel
- More and more stringent safety and performance requirements
- Excellence in quality is an obligation for fabrication
Fuel Assembly: A high quality ‘tailored’ product

Quality of interaction between the 3 parties is key to meet Safety, Reliability and Performance requirements.

Fuel is not an "off-the-shelf" product

Safety & Reliability & Performance

Fuel clad: 1st containment barrier

Utility
- Licensing
- Handling
- Operation

Fuel Supplier
- Design
- Modeling
- Licensing

Safety Authorities

Fuel Assembly:
A Brief on Fuel cycle

Context, obligations, possibilities potential interest of localization

Feedback on Fuel Cycle market and waste management
Setting realistic targets in terms of Localization of fuel cycle activities

**Motivations**

- Security of Supply is ensured by world fuels markets
- National added value and employement

**Obligations**

- Institutionnal : international instruments (treaties, conventions) on nuclear material
- Technical and industrial : capability and capacity building will take time
- Economical : scale effect, for each stage of the fuel cycle
  - The lower the flux, the higher the cost per unit

**Experience shows that the first candidate for localization generally considered is Fuel Fabrication**
Panorama of countries with a small nuclear capacity (2-3 GWe)

<table>
<thead>
<tr>
<th></th>
<th>Number of reactors</th>
<th>Generation capacity (MWe)</th>
<th>1st nuclear power generation</th>
<th>% Nuclear in the electricity mix</th>
<th>Fuel Fabrication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>2</td>
<td>935</td>
<td>1974</td>
<td>6.3%</td>
<td>YES</td>
</tr>
<tr>
<td>Brasil</td>
<td>2</td>
<td>1896</td>
<td>1985</td>
<td>3%</td>
<td>YES</td>
</tr>
<tr>
<td>Mexico</td>
<td>2</td>
<td>1600</td>
<td>1989</td>
<td>4%</td>
<td>NO</td>
</tr>
<tr>
<td>South Africa</td>
<td>2</td>
<td>1830</td>
<td>1984</td>
<td>5%</td>
<td>NO</td>
</tr>
<tr>
<td>Slovakia</td>
<td>4</td>
<td>1816</td>
<td>1972</td>
<td>50%</td>
<td>NO</td>
</tr>
<tr>
<td>Finland</td>
<td>4</td>
<td>2741</td>
<td>1977</td>
<td>30%</td>
<td>NO</td>
</tr>
</tbody>
</table>

Source: WNA, 2013

For such level of generation, rare are the countries having chosen to develop domestic nuclear fuel fabrication capability, even when the relative share of nuclear in the electricity mix is high.
Immediate priority locally rests With the safe management of spent fuel

<table>
<thead>
<tr>
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<th>BACK END</th>
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<th>FRONT END</th>
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<tbody>
<tr>
<td></td>
<td>Storage on site</td>
<td>Repository for high activity waste</td>
<td>Fuel Fabrication</td>
<td>Other Front End activities</td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brasil</td>
<td></td>
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<tr>
<td>Mexico</td>
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<td>South Africa</td>
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<tr>
<td>Finland</td>
<td></td>
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</table>

- Activ: ✔️
- Recently initiated: 🔴

Extending site storage capacity (pool or container) offers temporary solution while preparing for geological repository for ultimate wastes (spent fuel, vitrified waste after recycling)
Example: On-going programme in United Arab Emirates

- Programme includes 4 reactors 1400 MWe, 2 of them are under construction since 2012 et 2013 respectively.

- Front End: August 2012, ENEC signed several contracts for 15 years of operation from 2017 on:
  - Uranium concentrate: Uranium One, Rio Tinto, Areva, Tenex
  - Conversion: Converdyn, Tenex, Areva
  - Enrichment: Urenco, Areva, Tenex

- Fuel Fabrication:
  - By KNF (group KEPCO), associated to the supply of reactors by KEPCO,
  - Or Fuel fabrication factory in UAE

- Waste management: research programme for geological repository initiated with contribution of SKB

- The recycling option remains open
Example - Fabrication of PWR Fuel in China: Localizations in 30 years of cooperation with Areva

- 1985: Cooperation for construction
  - CNI23
  - 1992: Technology NI Daya Bay
  - CNNC
- 1994: Daya Bay CSD
  (Conteneurs Standard de Déchets)
- 1991: 1st agreement on Transfer of Technology (TT) on design of AFA2G
- 1998-2002: Agreement of design of AFA3G
- 1996: 1st Fabrication
  AFA 2G at CJNF - Yibin
- 1995: Nuclear Island (CP1, CP2, M310, P4, P4’ and N4)
  - CGNPC N4 French
- 2002: CSD Ling Ao
- 2005: Cooperation on the whole NI (extension du TT 1995)
  - CGNPC Ling Ao
- 2005: Digital control systems (TXS, TXP)
  - CGNPC
- 2008: TA On primary circuit
  - CGNPC
- 2007: Cooperation on the whole NI
  - CGNPC Technology EPR™ Taishan
- 2009: 18 months cycle management
  - CGNPC
- 2010: TT on zirconium tubes
- 2010: 1st Fabrication of AFA 3G at CNNFC-Baotou

Lengthy step by step process: Vision, Persistence and Patience
A Brief on Fuel cycle

Context, obligations, possibilities potential interest of localization

Feedback on Fuel Cycle markets and waste management
Natural uranium world production (tU)

- **Canada**: 9,100 tU, -4% since 2006
- **Kazakhstan**: 20,900 tU, +400% since 2006
- **Niger**: 4,800 tU, +39% since 2006
- **Namibia**: 4,300 tU, +77% since 2006
- **Australia**: 8,000 tU, +11% since 2006

**Top 6 countries**
85% of total

1. Kazakhstan 35%
2. Canada 15%
3. Australia 13%
4. Niger 8%
5. Namibia 7%
6. Russia 6%

Source: WNA & company reports

Diversified geopolitical risk
Countries with wide needs for uranium have scarce domestic resources

Uranium production places are distinct from uranium consumption places

Source: WNA, 2011
Market is split between at least 9 « big » suppliers

No shortage: almost all owners of uranium mines increased their production in 2012

1. AREVA available share: 92% Somaïr, 100% Katco, 100% Trekkopje, 47% Cominak, 30.2% McArthur and Lodève
Source: AREVA estimates from companies reports and WNA
A global mining footprint and 20 years of uranium resources for AREVA

A major, worldwide and diversified uranium producer and prospector
World Market for Conversion

Canada: CAMECO
- Capacity: ~11 000 tU/y

USA: ConverDyn
- Metropolis Works Plant (1959)
- Capacity: ~13 000 tU/y

UK: Cameco
- Springfields (1993)
- Capacity: ~5 000 tU/y

Russia: AtomEnergoProm
- Angarsk (1960) & Seversk (1952)
- Capacity: ~15 000 tU/y

France: AREVA
- Comurhex Malvesi (1959) & Pierrelatte (1961)
- Capacity: ~14 000 tU/y

China: CNNC
- Lanzhou & Diwopu (2008)
- Capacity*: ~3 000 tU/y
- Domestic needs

Others (Domestic needs and small capacities):
- Argentina (60 tU), Japan, Pakistan

Industrial capacity over 45 000 tU (UF6)/year, split between America, Europe and Asia

Sources: Trade Press et estimations AREVA
World Market for Enrichment

**Installed Capacities as of December 2013**

- **URENCO**
  - 3 factories in Europe: Germany, Netherlands, United Kingdom
  - 1 factory in USA
  - 17 MUTS/y

- **AREVA**
  - Georges Besse II
  - Eurodif closed
  - Project EREF
  - 5,5 MUTS/y (jusqu’à 7,5)

- **ROSATOM**
  - 4 factories: Zelenogorsk, Seversk, Novouralsk & Angarsk
  - 25 MUTS/y

- **JNFL**
  - 0,1 MUTS/y

- **CNNC**
  - 2,5 MUTS/y

**Sources:** Trade Press and AREVA estimates

 UTILITY = Unité de Travail de Séparation (SWU : Separative Work Unit)
World Market for Light Water Reactors

Market shares for LWRs
(sales in tU / y*)

Total Market: ~ 6 000 tons Uranium/y (figures 2012)

- AREVA: 32%
- Westinghouse - Toshiba*: 37%
- GNF**: 13%
- Others: 18%

* Westinghouse-Toshiba includes NFI & subcontracts to Enusa (Europe)
** GNF includes GNF-A (USA), GNF-J (Japan) & subcontracts to Genusa (Europe)

Source: Nuclear Assurance Corporation (Fuel Trac édition 10/2012); Données moyennes pour 2012+/− 1 an, d’après les assemblages de combustible frais chargés annuellement en réacteur.
AREVA’s place in the nuclear fuel market

127 of 300* PWRs and BWRs in operation worldwide use AREVA fuel

* Plan (275) + Mexico (2), Slovenia (1), South Korea (17), India (2), Iran (1) et Pakistan (2)
** Local manufacturer using AREVA technology

Source NAC IV-2013 (Number of reactors PWR and BWR supplied by AREVA / Total number of reactors)
Industrial solutions for responsible and sustainable management of spent fuel
Ready to serve the worldwide nuclear reactors fleet

**Sustainable Solutions for spent fuel management**

### Spent fuel treatment and waste minimisation
- Safe reduction of spent fuel stock and safe conditioning of waste
- Over 27,000 t of spent fuel treated
- Over 25,000 baskets for standard conditioning of ultimate waste

### Recycling for a better use of resources
- Up to +25% additional energy /TWh from spent fuel: recycled fuel, MOX and URT, with similar performance to that of UOx fuel
- Over 6,900 MOX fuel assemblies in more than 40 LWR in 40 years
- Over 7,300 URT fuel assemblies in more than 40 LWR in 40 years

### Safe Transportation and storage of nuclear material
- Over 7,000 transports each year, including 220 transports of spent fuel and UCs
- Over 50 transports of fresh MOX fuel assemblies each year
- Over 1,200 storage casks or transport in the log book, world leader with 50% of the U.S. market
Recycling is a safe way to manage ultimate waste

- **Thanks to recycling:**
  - Volume of ultimate waste is divided by 5
  - Toxicity of ultimate waste is divided by 10

- Basket for vitrified compacted waste: a standard container, **safe and stable** for the very long term

“Les déchets vitrifiés de la France représentent 5 grammes par habitant par an”

Foreign wastes are shipped back to the country of origin. French wastes are stored on site while waiting for the implementation of the national geological repository.
Dry spent fuel storage: example of NUHOMS modules
Conclusion
Conclusion

In the fuel cycle activities, localization targets should mainly concern, in priority

- Uranium production depending on available domestic resources
- Fuel fabrication
- Storage of spent fuel
- Management and storage of waste

Viability of uranium production and fuel fabrication activities should be carefully assessed, taking into consideration prices forecasts on the international markets

Long term process that should developed and implemented in a step by step manner
<table>
<thead>
<tr>
<th>Exploration et Exploitation Minières</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Avec plus de 300 000 tU livrées, AREVA est un partenaire minier de confiance pour un large éventail de clients</td>
</tr>
<tr>
<td>• Plateforme minière diversifié (géographiquement, technologiquement, plusieurs niveaux)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Services de Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Plus de 40 ans d’expérience de fabrication et ~ 400 000 tU livrées</td>
</tr>
<tr>
<td>• Le projet COMURHEX II avec 15 000 t/an monte en puissance (premiers ateliers en service en 2013 et 2014)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Services d’Enrichissement</th>
</tr>
</thead>
<tbody>
<tr>
<td>• La nouvelle usine Georges Besse II est rentrée en opération fin 2010 et a atteint 4,6 MUTS/an de capacité installée à l’automne 2013</td>
</tr>
<tr>
<td>• Capacité modulaire / adaptable au marché, basée sur la meilleure technologie mondiale de centrifugeuses (ETC)</td>
</tr>
<tr>
<td>• Plus de 200 MUTS livrées</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conception et Fabrication de Combustible</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Plus de 200 000 assemblages de combustible fabriqués</td>
</tr>
<tr>
<td>• Robustesse élevée, fiabilité et progrès continu grâce à l’expérience d’AREVA</td>
</tr>
<tr>
<td>• Plus de 35 ans d’expérience en REP et REB</td>
</tr>
</tbody>
</table>
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