Application of UNFC for the Classification of Uranium and REE (Th) Resources

Case study: Argentina
NUCLEAR GENERATION AND URANIUM DEMAND

REE (Th) PROJECTS/RESOURCES UNDER UNFC

URANIUM PROJECTS/RESOURCES UNDER UNFC

FINAL CONSIDERATIONS
Nuclear Power Generation

NPPs

➢ Installed capacity of 1.7 Gwe
➢ 10% share in the national electricity matrix
➢ Natural uranium requirements of about 220–250 tU per year

Source: CNEA, NA-SA, 2017
Nuclear Power Generation
SMD – CAREM

➢ 27 MWe net/32 MWe gross
➢ To come into operation in 2022
➢ To increase the scale of the unit to a higher capacity of possibly 120 MWe

Source: CNEA, 2018
➢ Generation capacity by 2035: 
  3.470 GWe (low) – 4.070 GWe (high) 
➢ Raw material needs by 2035: 
  525 tU (low) - 620 tU (high)

Source: NA-SA, 2017; CNEA, 2017
As part of the Reactor Power Regulation System, Embalse has 21 “Adjuster Rods”, loaded with pencils of natural Co-59 powder producing Co-60.

The normal Embalse production of Co-60 is around 3 million Ci/year.

In this and other eventual Candu-6 NPPs, part or all of such absorbing load could be replaced by Natural Thorium to produce U-233.

Source: Corcuera, 2011
NUCLEAR GENERATION AND URANIUM DEMAND

REE (Th) PROJECTS/RESOURCES UNDER UNFC

URANIUM PROJECTS/RESOURCES UNDER UNFC

FINAL CONSIDERATIONS
This case study specifically looks into how integrated REE and associated thorium projects could contribute to development of the solid minerals sector in Argentina.

The criteria of UNFC concerning social and economic viability (E), technical feasibility (F) and geological knowledge (G) were defined at the sub-category level, then grouped into the major classes considered in this classification system.

Source: UNECE, 2017
➢ REE is widely accepted as a critical material required for renewable energy technologies

➢ Uranium & Thorium could be used as fuel for low-carbon nuclear power generation

Source: Kelly, 2011; Thor Energy, 2013; Van Gosen et al., 2014; WNA, 2017
In connection with geological resources, in the 1950s and 1980s, CNEA undertook a number of specific thorium (REE) recognition studies on the detrital deposits along two rivers, due to nuclear fuel interest.

Source: Lucero, 1950; Santomero, 1978
Th-REE Orientation Surveys
III River – V River

➢ Resources evaluated based on raw material and monazite tonnages and monazite chemical compositions
➢ Limited quantities estimated are assumed to be currently unrecoverable
➢ UNFC class of “Additional Quantities in Place”

<table>
<thead>
<tr>
<th>Study Areas</th>
<th>III River</th>
<th>V River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Along River</td>
<td>135 km</td>
<td>46 km</td>
</tr>
<tr>
<td>Number of Samples</td>
<td>24</td>
<td>4</td>
</tr>
<tr>
<td>Raw Material Tonnage</td>
<td>46.2 Mt</td>
<td>3.58 Mt</td>
</tr>
<tr>
<td>Monazite Tonnage</td>
<td>25,480 t</td>
<td>6,260 t</td>
</tr>
<tr>
<td>Th Grade</td>
<td>0.0018%</td>
<td>0.0072%</td>
</tr>
<tr>
<td>REO Grade</td>
<td>0.0335%</td>
<td>---</td>
</tr>
<tr>
<td>Th Resources</td>
<td>850 t</td>
<td>260 t</td>
</tr>
<tr>
<td>REO Resources</td>
<td>15,500 t</td>
<td>---</td>
</tr>
</tbody>
</table>
➢ Thorium in Argentina has not been subject of systematic studies

➢ Anomalies, showings and deposits discovered as a result of uranium exploration

➢ Airborne radiometric surveys played a relevant role

➢ REE potential estimated as part of the examination of high-Th radiometric records and field geological characterization

Source: SEGEMAR 2017; López, 2004
Th-REE Exploration
Rodeo de los Molles Deposit

- Discovered by CNEA in the early 1980s while mapping and prospecting the area identified by regional airborne radiometric anomalies.

Source: Wealth Minerals Ltd., 2011; Viñas, Becchio, 1988; Lira et al., 1999
Largest undeveloped REE project in Argentina with geologic resource of 5.6 Mt of mineral ore.

Containing an approximate estimated 120,000 tREO and 1000 tU → Potentially Commercial Project.

About 10,000 tTh were estimated with a lesser degree of confidence → Exploration Project.

With the availability of additional data these quantities can be transferred to higher G categories and merged with the REE-U project.

**Th-REE Exploration**

Rodeo de los Molles Deposit

<table>
<thead>
<tr>
<th>UNFC Class</th>
<th>UNFC Sub-class</th>
<th>UNFC Category</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potentially Commercial Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>2,270 tREO, 15 tU</td>
</tr>
<tr>
<td>Exploration Project</td>
<td>---</td>
<td>E2, F2.2, G3</td>
<td>117,600 tREO, 950 tU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E3.3 F4 G4</td>
<td>10,000 tTh</td>
</tr>
</tbody>
</table>
The REE interest also covers vast areas of the Northwest of country in the Puna and Eastern Cordillera regions.

Focused mainly in Upper Jurassic-Cretaceous carbonatite rocks.

Source: Santomero, 1958, 1978; Zappettini, 1999
Inferred resources of around 24,000 tTh and 35,000 tREO+Y derive from nine mineral deposits.

Economic viability of extraction cannot yet be determined due to insufficient information and the justification as commercial developments may be subject to significant delay.

Hence, these projects are classified as “Non Commercial Projects” with sub-class “Development Unclarified”.
➢ International concern driven by the REE export restrictions of China
➢ Renewed worldwide interest in REE and junior companies have set up new exploration projects in Argentina
➢ Projects have shown encouraging geological prospects
## REE (Th) Projects Under UNFC

### Final Results

<table>
<thead>
<tr>
<th>Project</th>
<th>UNFC Class</th>
<th>UNFC Sub-class</th>
<th>UNFC Category</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rodeo de los Molles (REE-U)</td>
<td>Potentially Commercial Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>2,270 tREO 15 tU</td>
</tr>
<tr>
<td>Eastern Cordillera and Puna (REE-Th)</td>
<td>Non Commercial Project</td>
<td>Development Unclarified</td>
<td>E2, F2.2, G3</td>
<td>117,600 tREO 950 tU</td>
</tr>
<tr>
<td>III River (REE-Th)</td>
<td>Additional Quantities In Place</td>
<td>E3.2, F2.2, G3</td>
<td>35,300 tREO+Y 23,900 tTh</td>
<td></td>
</tr>
<tr>
<td>V River (Th)</td>
<td>Additional Quantities In Place</td>
<td>E3.3 F4 G4</td>
<td>15,500 tREO 850 tTh</td>
<td></td>
</tr>
<tr>
<td>Rodeo de los Molles (Th)</td>
<td>Exploration Project</td>
<td>E3.3 F4 G4</td>
<td>10,000 tTh</td>
<td></td>
</tr>
<tr>
<td>Jasimampa (REE-Th)</td>
<td>Exploration Project</td>
<td>E3.2, F3, G4</td>
<td>Not Available</td>
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</tr>
<tr>
<td>Susques (REE-Th)</td>
<td>Exploration Project</td>
<td>E3.2, F3, G4</td>
<td>Not Available</td>
<td></td>
</tr>
<tr>
<td>Cachi (REE-Th)</td>
<td>Exploration Project</td>
<td>E3.2, F3, G4</td>
<td>Not Available</td>
<td></td>
</tr>
<tr>
<td>Cueva del Chacho (REE-Th)</td>
<td>Exploration Project</td>
<td>E3.2, F3, G4</td>
<td>Not Available</td>
<td></td>
</tr>
</tbody>
</table>

- Potentially Commercial Projects (Development On Hold)
- Non Commercial Projects (Development Unclarified)
- Exploration Projects
- Additional Quantities In Place
Uranium and Associated Critical Materials
UNFC Application

➢ Uranium exploration projects
➢ Main uranium projects
➢ Other potential sources of uranium

Source: UNECE, 2017
At the exploration level, projects in the country are carried out by both the private sector and the government. As a general rule, the integral exploration at basin level has not been carried out. Evaluated resources are meager compared to the country's uranium potential. Resources have generally been evaluated with a low level of confidence.

Source: CNEA, 2014-2017
➢ To advance the delineation of resources
➢ To raise the level of confidence of resources
➢ To carry out Preliminary Economic Assessments
➢ To focus on In Situ Leaching projects

The most advanced exploration projects have a high potential of transforming to a higher degree of maturity as classified in the UNFC system
### Main Uranium Projects (G1,G2,G3)

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Type</th>
<th>UNFC: G1,2 RAR tU ≤ USD 130/kgU</th>
<th>UNFC: G3 IR tU ≤ USD 130/kgU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sierra Pintada</td>
<td>Volcanic-related</td>
<td>3,900</td>
<td>6,110</td>
</tr>
<tr>
<td>Cerro Solo</td>
<td>Sandstone</td>
<td>4,420</td>
<td>3,760</td>
</tr>
<tr>
<td>Don Otto</td>
<td>Sandstone</td>
<td>180</td>
<td>250</td>
</tr>
<tr>
<td>Laguna Colorada</td>
<td>Volcanic-related</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>Laguna Salada</td>
<td>Surficial</td>
<td>2,420</td>
<td>1,460</td>
</tr>
<tr>
<td>Meseta Central</td>
<td>Sandstone</td>
<td>-</td>
<td>7,350</td>
</tr>
<tr>
<td>Amarillo Grande</td>
<td>Sandstone/Surficial</td>
<td>-</td>
<td>7,360</td>
</tr>
<tr>
<td>Sub Total</td>
<td></td>
<td>11,020 tU</td>
<td>26,350 tU</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>37,370 tU</strong></td>
<td></td>
</tr>
</tbody>
</table>

Source: NEA – IAEA, 2016; U3O8 Corp, 2015; UrAmerica, 2013-2015; Blue Sky, 2018; UNECE 2012-2018
Technical Feasibility
Main Uranium Projects (F2.1, F2.2)

- Cerro Solo (U, Mo) Chubut
  UNFC: F2.1
  ➢ Pre Feasibility (Stand By)

- Laguna Salada (U, V) Chubut
  UNFC: F2.1
  ➢ NI 43-101: Exploration Results, RAR, IR, PEA

- Amarillo Grande (U, V) Río Negro
  UNFC: F2.2
  ➢ NI 43-101: Exploration Results, IR, PEA In Progress

- Sierra Pintada (U) Mendoza
  UNFC: F2.2
  ➢ Adverse Legal Framework (Stand By), Remediation

- Meseta Central (U) Chubut
  UNFC: F2.2
  ➢ NI 43-101: Exploration Results, IR

- Don Otto (U, V) Salta
  UNFC: F2.2
  ➢ Comprehensive Project (Formulation)
Projects with a higher degree of maturity must complete technical feasibility studies for the recovery of uranium

In the case of possible future production of U, other valuable materials such as V and Mo, can be assumed to be produced as a by- or co-product, contributing to the mineral sector development in Argentina

While U is used for nuclear fuel, V and Mo have critical applications, especially in the renewable energy and steel industry sectors
Social and Economic Viability
Uranium Prices

➢ Uranium Production of Argentina: 2,600 tU (1952–1997)

Price 10/2018 = USD 27.9/lb U3O8 = USD 72.5/kg U

Source: UxC, 2018; CNEA, 2014
**Nuclear Fuel**

1997 - Present

**Yellowcake (UOC) Imports**
- Canada, Czech Rep, Kazakhstan, Uzbekistan

**UO2 Conversion Facility**
- DIOXITEK S.A.

**Fuel Fabrication Facility**
- CONUAR S.A.

**D₂O Facility**
- ENSI S.E.

Source: CNEA, 2017; DIOXITEK, 2018; CONUAR, 2018
Prices in the international market should be taken as a reference, not as a determining factor.

Raw material has a bearing of 5 to 7 per cent in the total cost of nuclear energy in the country (USD 80–100/MWh).

So far, Argentina has not run after the objective to obtain dividends from the sale of uranium in international markets.

National, provincial and local taxes payable return to the State.
Social and Economic Viability
FOB Vs. Uranium Prices

Average FOB Prices
International Uranium Prices

Source: Ministerio de Energía y Minería, 2016
Uranium Imports
Evolution of Expenditures

Source: Ministerio de Energía y Minería, 2016
Uranium identified resources (G1, G2, G3) are mostly located in provinces where no metallic mineral mining projects are in operation, and also, the provincial legislations markedly restrict uranium production.

Mining laws could be amended as necessary if a requirement of mining (uranium and other metals) projects becomes very important to the country.
Unconventional sources of uranium that could provide sustainable alternatives for nuclear supply in the foreseeable future, such as rare earth projects, phosphates, and lake and sea waters.

Source: Kelly, 2011; Thor Energy, 2013; Van Gosen et al., 2014; WNA, 2017
IAEA project CRP on neutral uses of HTGRs
➢ Assessment of the uranium potential of phosphate rocks and testing low-grade phosphate ores extraction

Source: IAEA, 2015-2018; CNEA, 2015-2018
Improved adsorbent materials for recovery of uranium from sea/lake waters

R+D projects in Japan, the USA and China

Innovate Perspective

Other Potential Sources of Uranium
Argentina Continental Shelf: 2,800,000 Km²!

Sovereign rights for commercial exploitation:

- metallic-ore
- non-metallic ore
- hydrocarbon extraction
- so on …
Uranium Projects Under UNFC
Final Results

- **Potentially Commercial Projects** (Development Pending)
- **Potentially Commercial Projects** (Development On Hold)
- **Non Commercial Projects** (Development Unclarified)
- **Non Commercial Project** (Development Not Viable)
- **Exploration Projects**
- **Additional Quantities In Place**

### Projects Summary

<table>
<thead>
<tr>
<th>Project</th>
<th>UNFC Class</th>
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<th>UNFC Category</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerro Solo (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development Pending</td>
<td>E2, F2.1, G1</td>
<td>2,420 tU</td>
</tr>
<tr>
<td>Cerro Solo (U)</td>
<td>Non-Commercial Projects</td>
<td>Development Unclarified</td>
<td>E2, F2.2, G2</td>
<td>2,000 tU</td>
</tr>
<tr>
<td>Cerro Solo (Mo)</td>
<td>Potentially Commercial Projects</td>
<td>Development Unclarified</td>
<td>E2, F2.1, G3</td>
<td>4,810 tU</td>
</tr>
<tr>
<td>Lagua Salada (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development Unclarified</td>
<td>E2, F2.1, G2</td>
<td>2,420 tU</td>
</tr>
<tr>
<td>Lagua Salada (U)</td>
<td>Exploration Project</td>
<td>Development Unclarified</td>
<td>E2, F2.2, G2</td>
<td>14,500 tU</td>
</tr>
<tr>
<td>Laguna Salada (Mo)</td>
<td>Non-Commercial Projects</td>
<td>Development Unclarified</td>
<td>E2, F2.2, G3</td>
<td>870 tMo</td>
</tr>
<tr>
<td>Sierra Pintada (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G1</td>
<td>2,700 tU</td>
</tr>
<tr>
<td>Sierra Pintada (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>1,200 tU</td>
</tr>
<tr>
<td>Masiata (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G3</td>
<td>6,110 tU</td>
</tr>
<tr>
<td>Don Otto (V)</td>
<td>Non Commercial Projects</td>
<td>Development Not Viable</td>
<td>E3.2, F2.2, G3</td>
<td>7,350 tU</td>
</tr>
<tr>
<td>Don Otto (U)</td>
<td>Non Commercial Projects</td>
<td>Development Not Viable</td>
<td>E3.2, F2.2, G1</td>
<td>100 tU</td>
</tr>
<tr>
<td>Don Otto (V)</td>
<td>Non Commercial Projects</td>
<td>Development Not Viable</td>
<td>E3.2, F2.2, G2</td>
<td>80 tU</td>
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<td>Don Otto (U)</td>
<td>Non Commercial Projects</td>
<td>Development Not Viable</td>
<td>E3.2, F2.2, G3</td>
<td>250 tU</td>
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<tr>
<td>Laguna Colorada (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G1</td>
<td>2,700 tU</td>
</tr>
<tr>
<td>Laguna Colorada (U)</td>
<td>Exploration Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>14,500 tU</td>
</tr>
<tr>
<td>San Jorge Basin (U)</td>
<td>Exploration Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G3</td>
<td>1,500 - 2,500 tU</td>
</tr>
<tr>
<td>Neuquen Basin (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G1</td>
<td>2,700 tU</td>
</tr>
<tr>
<td>Neuquen Basin (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>14,500 tU</td>
</tr>
<tr>
<td>Neuquen Basin (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G3</td>
<td>1,500 - 2,500 tU</td>
</tr>
<tr>
<td>Mina Franca (U)</td>
<td>Exploration Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G1</td>
<td>2,700 tU</td>
</tr>
<tr>
<td>Mina Franca (U)</td>
<td>Exploration Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>14,500 tU</td>
</tr>
<tr>
<td>Mina Franca (U)</td>
<td>Exploration Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G3</td>
<td>1,500 - 2,500 tU</td>
</tr>
<tr>
<td>Laguna Sirven (U,V)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G1</td>
<td>2,700 tU</td>
</tr>
<tr>
<td>Laguna Sirven (U,V)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>14,500 tU</td>
</tr>
<tr>
<td>Laguna Sirven (U,V)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G3</td>
<td>1,500 - 2,500 tU</td>
</tr>
<tr>
<td>Sierra Pintada (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G1</td>
<td>2,700 tU</td>
</tr>
<tr>
<td>Sierra Pintada (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>14,500 tU</td>
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<tr>
<td>Sierra Pintada (U)</td>
<td>Potentially Commercial Projects</td>
<td>Development On Hold</td>
<td>E2, F2.2, G3</td>
<td>1,500 - 2,500 tU</td>
</tr>
<tr>
<td>Rodeo de los Molles (REE-U)</td>
<td>Potentially Commercial Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G1</td>
<td>2,270 tREO</td>
</tr>
<tr>
<td>Rodeo de los Molles (REE-U)</td>
<td>Potentially Commercial Project</td>
<td>Development On Hold</td>
<td>E2, F2.2, G2</td>
<td>950 tU</td>
</tr>
<tr>
<td>Uranium from phosphates</td>
<td>Additional Quantities In Place</td>
<td>…</td>
<td>E3.3, F4, G4</td>
<td>Not Available</td>
</tr>
<tr>
<td>Uranium from porphyry copper</td>
<td>Additional Quantities In Place</td>
<td>…</td>
<td>E3.3, F4, G4</td>
<td>Not Available</td>
</tr>
<tr>
<td>Uranium from coal</td>
<td>Additional Quantities In Place</td>
<td>…</td>
<td>E3.3, F4, G4</td>
<td>Not Available</td>
</tr>
<tr>
<td>Uranium from sea/lake water</td>
<td>Additional Quantities In Place</td>
<td>…</td>
<td>E3.3, F4, G4</td>
<td>Not Available</td>
</tr>
</tbody>
</table>
NUCLEAR GENERATION AND URANIUM DEMAND

REE (Th) PROJECTS/RESOURCES UNDER UNFC

URANIUM PROJECTS/RESOURCES UNDER UNFC

FINAL CONSIDERATIONS
When mapping REE (Th) resources in the UNFC scheme, the Argentine projects currently have neither economic and social conditions nor technical feasibility that are sufficiently matured to indicate a reasonable potential for commercial recovery and sale in the foreseeable future, except for the Rodeo de los Molles project.

However, when looking from the perspective of comprehensive extraction, there are projects with significant potential for future development, thereby increasing the maturity of the combined project.
Final Considerations

➢ While REE has crucial applications, especially in the renewable energy sector, the Th produced can be stored for future use in R&D projects or nuclear power generation.

➢ The role that REEs could contribute to Argentina’s GDP in the future could be reassessed with this in mind.

➢ The apparent growth prospects for the use of nuclear energy to generate electricity in Argentina, would lead to a doubling of the uranium requirements by 2035.

➢ There are no immediate prospects for the provision of nuclear raw material for fuel fabrication from the production of uranium oxide concentrates from domestic deposits.
Currently, uranium is imported for domestic use in Argentina, which has implications for supply and energy security.

For this reason, this report has tried to outline different possibilities for the sustainable domestic production of uranium, especially considering the comprehensive extraction of other associated critical material, notably molybdenum and vanadium.

In this general context, the application of UNFC contributes to both a better understanding of the availability of reliable resources in Argentina as well as demonstrate how these resources can contribute to the national nuclear and renewable energy program and the mining sector.
Thank you!

Luis LÓPEZ
Project Management Division, Head
National Atomic Energy Commission, Argentina
Date 12I 11 | 2018, Geneva