Fuel Development at CRL

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Acknowledgements

- Fuel Development
- Hot Cells
- Analytical Chemistry
- Many more
Outline

- Nuclear Plant
- Fuel in CANDU
- Fuel Development
- Advanced Fuel Cycles
Producing Electricity with Fossil Fuel Plant
Producing Electricity with Nuclear Plant
CANDU Reactor Core

- Heavy Water Moderator and Coolant
- Large heat sinks
- On-power Fueling
- Modular Design
- Simple fuel bundle
- Calandria Tube
- Pressure Tube
- Fuel
Fuel Channel Arrangement

- Calandria Tube
- Pressure Tube
- Annulus Gas
- Fuel Bundle
- Heavy Water Moderator
- Heavy Water Coolant
- Annulus Spacer
Nuclear Fission

“Slow” Neutron

Uranium 235

Heat

Fission Products

“Fast” Neutrons

UNRESTRICTED / ILLIMITÉ
Heavy Water Moderates the Reaction

Fast Neutrons

Slow Neutrons

Fission Products

Uranium 235
URANIUM FUEL

HEAVY WATER (coolant)

HEAVY WATER (moderator)

CONTROL RODS
37-element bundle

Length = 0.5 m
Weight = 24 kg
Diameter = 10 cm
$\text{UO}_2$ Pellet
43-element CANFLEX fuel bundle
- same diameter and length as CANDU Classic
- greater subdivision for higher thermal margin
- 42 elements contain 2.4 wt% LEU
- larger centre element contains yttrium-stabilised matrix of Zirconium oxide + Dy₂O₃ + Gd₂O₃

Reference burn-up
~20,000 MWd/te
Bearing-Pads, Spacer-Pads
Fuel Development

- Conceptualization, development and testing of nuclear fuel
- Support utilities – fuel surveillance
- Research reactor fuel
- NOC
Advanced Fuel Cycle Program at CRL

- Extend energy resources beyond what is capable with current technologies
- Generate S&T for the purpose of:
  - Expand limits of fuel utilization
  - Deploy alternative fuel cycles based on more abundant elements
  - Increase fuel flexibility
  - Employ recycled fuels
Advanced Fuel Cycle Program at CRL

- Improve environmental sustainability
- Increase public return on investment
  - Less expensive alternatives for reprocessing, plant maintenance
- Take advantage of Canadian innovations
- Optimize and utilize technology from the rest of the world
The Fuel Cycle

- **Mining**
- **Milling**
- **Conversion**
- **Enrichment**
- **Fuel fabrication**
- **Power Plant**
- **Electricity**
- **Spent fuel storage**
- **Reprocessing**
- **Recycle**
- **High-level waste**

For natural uranium fuels
CANDU Advanced Fuel Cycles

- Enriched Fuel (3.5%)
- Slightly Enriched Uranium Fuel (0.9 to 1.2%)
- DUPIC Fuel (0.9% U, 0.6% Pu)
- Recovered Uranium (0.9%)
- Plutonium Recycling
- Spent LWR Fuel
- Dry Processing
- Actinide Burning
- Uranium Mine
- Natural Fuel
- Natural Uranium 0.7% U235
- Thorium Cycle
- Uranium Mining
- Enrichment
- Reprocessing

Actinide Burning

Plutonium Recycling

UNRESTRICTED / ILLIMITÉ
Why Advanced Fuel Cycles?

- Approximately 440 operating units, generating ≈2,700 TWh of nuclear electricity

- At least a 10 times expansion of nuclear energy utilization is required by 2050 (IAEA Study)

- Alternative fuel cycle options are needed to ensure the availability of long-term fuel resources


AECL’s Experience in Advanced Fuel Cycles

- Recycled Uranium (NUE, DUPIC)
- Thoria (mixed with U or Pu)

- Two fuels are the focus of current collaborative work with China:
  - LEU/Thorium Fuel Program
  - Natural Uranium Equivalent (NUE) Fuel Program
- Currently, the NUE fuel program is ongoing in the Qinshan 3 reactor and the LEU/Th fuel program is being evaluated for its technical feasibility
DUPIC Fuel Cycle Concept
DUPIC – Direct Use of spent PWR fuel in CANDU

- DUPIC fuel pellet fissile content
  - 0.79 wt.% U-235 in total U
  - 0.91 wt.% Pu in total HE

DUPIC experimental fuel, BB02, burnup: 517 MWh/kgHE
From PWR fuel with 670 MWh/kgU

BB04, (49 kW/m)
BB02, (51 kW/m)
Thorium

Why Thorium?

• More abundant than uranium
  • e.g. USA, Turkey, India, Brazil, Venezuela, Norway

• Attractive to countries having thorium reserves

• Uranium price is increasing as reserves are used

• CANDU flexible fuel cycles includes Th-based fuel

World Distribution of Thorium Reserves
Source: Nuclear Engineering International
Thorium in CANDU

- AECL R&D over the past 50 years on thorium use in CANDU reactors

- CANDU’s excellent neutron economy - basis for the efficient use of either an LEU or Pu driver in thorium fuel cycles

- Simplest application of thorium in the CANDU reactor is via a first pass fuel cycle

- Over time and through evolutionary modifications, the CANDU reactor can be optimized for thorium operation in a recycling mode
Thorium Physics

- No intrinsic fissile component

- Fissile component must be added

- U-233, U-235 or Pu-239 must be:
  - *in the vicinity of Th fuel, or*
  - *blended with Th fuel*

- Th vs. U irradiation:
  - *Th-232 replaces U-238 as fertile component*
  - *U-233 replaces Pu-239 as bred fissile component*
C6, EC6, ACR and SCWR: Multiple Fuel Configurations

Suitable for C6/EC6, ACR and SCWR
BDL-422 (Th, Pu)O₂ Bundle

Centre element replaced with guide tube to facilitate irradiation in NRU
BDL-422 (Th, Pu)O₂ experiment

- BDL-422 (Th, Pu)O₂ experiment supports the thorium component of the AECL advanced fuel cycles program
- Six-37 element bundles fuelled with (Th, Pu)O₂ were fabricated in the Recycle Fuel Fabrication Laboratories
- The bundles were designated ADA, ADB, ADC,ADD ADE and ADF
- The six bundles were irradiated in the NRU reactor under CANDU normal operating conditions to:
  - burnups ranging from 450 MWh/kgHE (19 MWd/kgHE) to 1181 MWh/kgHE (49 MWd/kgHE)
  - peak element linear power ratings ranging from 52 kW/m to 73 kW/m


Thoria-Plutonia – Grain morphology

- (Th, Pu)O$_2$ at pellet centre
  - Equiaxed Grains
  - ~3 times as-fabricated grain size

(Th, Pu)O$_2$ - Equiaxed Grains (67 kW/m)
UO$_2$ – Extensive Columnar Grains (65 kW/m)
(U, Pu)O$_2$ - Columnar Grains (63 kW/m)
Urania-Plutonia (MOX)

- Example: To investigate effect of Pu homogeneity on MOX fuel performance.
- Irradiate pellets with 3 different levels of homogeneity under CANDU powers (~50kW/m) but higher burnup (21 MWd/kgHE)

Type A
Homogeneous

Type B
Islands of Master Mix

Type C
Islands of Pure PuO₂
Advanced Fuel Cycle
Fuel Development

- NOC Nuclear Fuel
- Support utilities
- Research reactor fuel
- S&T for the Public Good
THANK YOU!

AECL  EACL