CHINA’S NUCLEAR POWER PROGRAM
中国核电工程

Presentation to the Canadian Nuclear Society
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AECL CRL
"Perhaps, no other nuclear industry is as difficult to write about as that of China."

From the US Energy Information Administration
1. BACKGROUND

- Power Situation in China until 2005

Power Composition (%) in 2005

- Fossil fuels mainly coal
- Hydro
- Nuclear

Total Installed Power Capacity, 500 GW

Current Difficulties in China

- Sever pollution – Coal fired power plants as the big contributor
  16 out of 20 the world most polluted cities in China.
- Rolling blackouts came back in the coastal area since 2002.
- 10 million population in remote areas – still no access to power.
1. BACKGROUND

- Power shortage - persisted before 1970s
  Power shortage in Shanghai.
  Logistic challenge for the city.
- Geographical reality
  Power demand mainly in coastal areas.
  Main energy reserve in inland areas.
2. MAJOR COMPONENTS in the China’s Nuclear Power Program

- Localization - Local designs and local components. (Diversity, Learning and Standardization).
- Nuclear plant construction and operation.
- Uranium enrichment.
- Fuel reprocessing and cycle.
- Waste management and disposal.
- Generation IV program – including fast breeder and high temperature reactor.
- Fusion technology.
- Hybrid fusion-fission technology.
3. THE FUEL – URANIUM

- Uranium first found in Guangxi.
- Uranium reserve – very limited resources.
3. THE FUEL – URANIUM

The Northwest Uranium Enrichment Plant (in GanSu Province), 西北铀浓缩厂
3. THE FUEL – URANIUM
Reserve and Demand

- Total Uranium reserve: 77,000 tons
  Only feed the existing reactors for 46 years
- With future Uranium demands
  Only enough – 9 years at the level of 2020.
  Only enough – 4 – 5 years at the level of 2040.

<table>
<thead>
<tr>
<th>Year</th>
<th>Nuclear Capacity (GW)</th>
<th>Nuclear Share (%)</th>
<th>U Consumption (tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>7-8</td>
<td>~1.6</td>
<td>1,650</td>
</tr>
<tr>
<td>2010</td>
<td>14</td>
<td>~2</td>
<td>2,500</td>
</tr>
<tr>
<td>2020</td>
<td>40</td>
<td>4</td>
<td>8,250</td>
</tr>
<tr>
<td>2040$^1$</td>
<td>83</td>
<td>5.5</td>
<td>15,000</td>
</tr>
<tr>
<td>2040$^2$</td>
<td>120</td>
<td>8</td>
<td>22,000</td>
</tr>
</tbody>
</table>
3. THE FUEL – URANIUM

China-Australia Uranium Deal
3. THE FUEL – URANIUM

Reprocessing

Locations: GanSu, Sichuan, XinJiang
3. THE FUEL – URANIUM
Fuel Reprocessing

• **Two facilities** in Gansu province
  - Operational in 1966 currently closed down.

• **China's largest plant** in Sichuan province
  - Operational around 1974 and in 1999 decided to be decommissioned.

• **GOBI DESERT facility-I**, a pilot plant with a capacity of processing 100 kg of uranium per day completion in 1995.

• **GOBI DESERT facility-II**, a pilot plant with a capacity of 50-100 tons of spent fuel per year completion around 2000.

• The mothballed German mixed oxide (MOX) fuel reprocessing and fabrication Siemens Hanau plant **announced sale** to China in 2003.

• **Lanzhou pilot plant (Gansu province)** - throughput of 100 to 400 kilograms of low enriched uranium (LEU) per day operational in 2006.
4. CURRENT STATUS

Worldwide Nuclear Power Units and Output by Nation by 2006

<table>
<thead>
<tr>
<th>No.</th>
<th>Nation</th>
<th># Units</th>
<th>Power Capacity (MWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>USA</td>
<td>104</td>
<td>100,460</td>
</tr>
<tr>
<td>2</td>
<td>France</td>
<td>59</td>
<td>63,363</td>
</tr>
<tr>
<td>3</td>
<td>Japan</td>
<td>53</td>
<td>45,218</td>
</tr>
<tr>
<td>4</td>
<td>Russia</td>
<td>31</td>
<td>20,843</td>
</tr>
<tr>
<td>5</td>
<td>Germany</td>
<td>18</td>
<td>20,643</td>
</tr>
<tr>
<td>6</td>
<td>Canada</td>
<td>22</td>
<td>15,222</td>
</tr>
<tr>
<td>7</td>
<td>South Korea</td>
<td>19</td>
<td>15,850</td>
</tr>
<tr>
<td>8</td>
<td>Ukraine</td>
<td>15</td>
<td>13,200</td>
</tr>
<tr>
<td>9</td>
<td>UK</td>
<td>23</td>
<td>11,852</td>
</tr>
<tr>
<td>10</td>
<td>Sweden</td>
<td>10</td>
<td>8,938</td>
</tr>
<tr>
<td>11</td>
<td>China</td>
<td>10</td>
<td>7,587</td>
</tr>
<tr>
<td>12</td>
<td>Spain</td>
<td>8</td>
<td>7,442</td>
</tr>
<tr>
<td>13</td>
<td>Belgium</td>
<td>7</td>
<td>5,728</td>
</tr>
</tbody>
</table>
4. CURRENT STATUS

Overview on Existing and Approved NPP

- **Haiyang**
  - 2X1000 MW

- **Tianwan**
  - 2X1000 MW

- **Qinshan**
  - Phase I 300 MW
  - Phase II 2 X 600 MW
  - Phase III 2 X 700 MW
  - Phase IV 2 X 650 MW

- **Sanmen**
  - 2X1000 MW

- **HuiAn**
  - 2X1000 MW

- **Daya Bay**
  - 2X982 MW

- **Ling Ao**
  - 2X982 MW

- **Yangjiang**
  - 6X1000 MW
### 4. CURRENT STATUS

Existing NPP in China

<table>
<thead>
<tr>
<th>Stations</th>
<th>Power Output (MWe)</th>
<th>Reactor Type</th>
<th>Supplier</th>
<th>Owner</th>
<th>In-Service Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qinshan Phase I</td>
<td>310</td>
<td>PWR</td>
<td>CNNC¹</td>
<td>CNNC</td>
<td>Dec 1991</td>
</tr>
<tr>
<td>Daya Bay Units 1 and 2</td>
<td>2 x 984</td>
<td>PWR</td>
<td>Framatome</td>
<td>CGNPC</td>
<td>Unit 1 in Aug 1993</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unit 2 in Feb 1994</td>
</tr>
<tr>
<td>LingAo Units 1 and 2</td>
<td>2 x 990</td>
<td>PWR</td>
<td>Framatome</td>
<td>CGNPC</td>
<td>Unit 1 in Feb 2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unit 2 in Dec 2002</td>
</tr>
<tr>
<td>Qinshan Phase II Units 1</td>
<td>2 x 650</td>
<td>PWR</td>
<td>CNNC²</td>
<td>CNNC</td>
<td>Unit 1 in Feb 2002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unit 2 in Mar 2004</td>
</tr>
<tr>
<td>Qinshan Phase III Units</td>
<td>2 x 728</td>
<td>CANDU</td>
<td>AECL</td>
<td>CNNC</td>
<td>Unit 1 in Dec 2002</td>
</tr>
<tr>
<td>Units 1 and 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unit 2 in Jul 2003</td>
</tr>
<tr>
<td>Tianwan Units 1 and 2</td>
<td>2 x 1060</td>
<td>VVER PWR (Russian)</td>
<td>ASE</td>
<td>CNNC</td>
<td>Unit 1 in May 2006³</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unit 2 expected in 2007</td>
</tr>
</tbody>
</table>

¹ Based on French and US Technology
² Based on French design
³ Originally scheduled for 2004
4. CURRENT STATUS

Phase IV under construction (2006~) 2XCNP-600 MW Qinshan (秦山)

Qinshan Phase I Unit – 310 MW

Qinshan Phase II Units – 2 X 650 MW

Qinshan Phase III – Two Candu-6 Units – 2 X 730 MW
4. CURRENT STATUS

Existing NPP - Daya Bay (大亚湾)

Two units: 984 MWe each
Vendor – Framatome.
4. CURRENT STATUS – Ling Ao (岭澳)
Phase II under construction (2005~) 2XCNP-1000 MW

Two Units – 990 MWe each
Vendor - Framatome
4. CURRENT STATUS
Existing NPP – Tianwan (田湾)

Two Units – 1000 MWe each
Vendor - ASE

Photo taken Sept. 2003

Photo taken 2006
5. TIMELINE OF THE CHINESE NUCLEAR POWER

- 1981 - A proposal submitted to build a 300 MW PWR at Haiyan (Qinshan 1); the first nuclear reactor connected to the grid in 1991.
- 2000 - 16 billion kwhrs.
- 2004 - NDRC planned to add at least 2 more reactors per year for the next 16 years until 2020.
- 2010 – Quadruple the level of 2000 to 66 billion kwhrs.
- 2020 - Climbs to 142 billion Kwhr 9 fold the level of 2000.
- 2040 – Treble the level in 2020 or 20 fold the level of 2000.
Not shown: Pakistan, projected 4.3 GW by 2020, North Korea, projected 5.7 GW by 2020.
## 6. INFRASTRUCTURE

### CHINA'S RESEARCH REACTORS

#### CHINA INSTITUTE OF ATOMIC ENERGY (CIAE), Beijing

<table>
<thead>
<tr>
<th>Unit</th>
<th>Type(s)</th>
<th>Operator</th>
<th>Fuel</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Power Fast Reactor</td>
<td>Fast critical</td>
<td>CIAE</td>
<td>90% HEU</td>
<td>0.05 kW</td>
</tr>
<tr>
<td>CEFR</td>
<td>FBR (under construction)</td>
<td>(under construction)</td>
<td>60% HEU</td>
<td>65 MW</td>
</tr>
<tr>
<td>HWRR-2</td>
<td>Heavy water</td>
<td>IAE</td>
<td>3 % LEU</td>
<td>15 MW</td>
</tr>
<tr>
<td>MNSR-IAE</td>
<td>Tank-in-pool (same)</td>
<td>(same)</td>
<td>90% HEU</td>
<td>27 kW</td>
</tr>
<tr>
<td>SPR-IAE</td>
<td>Pool (same)</td>
<td>(same)</td>
<td>10% LEU</td>
<td>3.5 MW</td>
</tr>
<tr>
<td>CARR</td>
<td>NG RR (under construction)</td>
<td>(under construction)</td>
<td>LEU</td>
<td>60 MW</td>
</tr>
</tbody>
</table>

### INSTITUTE OF NUCLEAR ENERGY TECHNOLOGY (INET), Tsinghua University

<table>
<thead>
<tr>
<th>Unit</th>
<th>Type(s)</th>
<th>Operator</th>
<th>Fuel</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTHHR (NHR-5)</td>
<td>Heating prototype</td>
<td>INET</td>
<td>3% LEU</td>
<td>5 MWth</td>
</tr>
<tr>
<td>Tsinghua Reactor</td>
<td>Pool-2 cores</td>
<td>INET</td>
<td>10% LEU</td>
<td>2.8 MW</td>
</tr>
<tr>
<td>HTR-10</td>
<td>HGTR</td>
<td>INET</td>
<td>17% LEU</td>
<td>10 MWth</td>
</tr>
</tbody>
</table>
6. INFRASTRUCTURE
CHINA'S RESEARCH REACTORS

SOUTHWEST REACTOR ENGINEERING RESEARCH AND DESIGN ACADEMY (FIRST ACADEMY), Jiajiang, Sichuan Province

<table>
<thead>
<tr>
<th>Unit</th>
<th>Type(s)</th>
<th>Operator</th>
<th>Fuel</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFETR</td>
<td>Tank</td>
<td>First Academy</td>
<td>93% HEU [1]</td>
<td>125 MWth</td>
</tr>
<tr>
<td>HFETR Critical</td>
<td>Critical assembly</td>
<td>First Academy</td>
<td>90% HEU</td>
<td>0 kW</td>
</tr>
<tr>
<td>PPR Pulsing</td>
<td>Pool UZRH</td>
<td>First Academy</td>
<td>20% MEU</td>
<td>1 MW</td>
</tr>
<tr>
<td>SPRR-300</td>
<td>Pool</td>
<td>First Academy</td>
<td>10% LEU</td>
<td>3.7 MW</td>
</tr>
<tr>
<td>MJTR</td>
<td>Pool</td>
<td>First Academy</td>
<td>90% HEU</td>
<td>5 MW</td>
</tr>
<tr>
<td>Zero Power Reactor</td>
<td>Critical assembly</td>
<td>First Academy</td>
<td>Shutdown</td>
<td></td>
</tr>
</tbody>
</table>

[1] China has reportedly told US officials that it plans to convert the HFETR to use LEU fuel.
## 6. INFRASTRUCTURE

### CHINA'S RESEARCH REACTORS

#### SHANDONG GEOLOGY BUREAU

<table>
<thead>
<tr>
<th>Unit</th>
<th>Type(s)</th>
<th>Operator</th>
<th>Fuel</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNSR-SD</td>
<td>Tank-in-pool</td>
<td>Shandong Geology Bureau</td>
<td>90% HEU</td>
<td>27 kW</td>
</tr>
</tbody>
</table>

#### SHENZHEN UNIVERSITY

<table>
<thead>
<tr>
<th>Unit</th>
<th>Type(s)</th>
<th>Operator</th>
<th>Fuel</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNSR-SZ</td>
<td>Tank-in-pool</td>
<td>Shenzhen University</td>
<td>90% HEU</td>
<td>27 kW</td>
</tr>
</tbody>
</table>
6. INFRASTRUCTURE

Nuclear Authorities

THE STATE COUNCIL – FINAL APPROVAL

• China Atomic Energy Authority (CAEA) - New plant feasibility studies
  1. Planning & Managing nuclear energy
  2. Reviewing & Approving feasibility studies for new plants
  3. Promoting International Cooperation

• National Nuclear Safety Administration (NNSA) - Sitting proposals
  1. Licensing and regulations
  2. Maintaining international agreements regarding safety

• National Development and Reform Commission (NDRC) – Project proposals
  Project approvals

• State Environmental Protection Administration (SEPA) - Environmental studies
  1. Radiological monitoring
  2. Radioactive waste management
6. INFRASTRUCTURE

Major Nuclear Research and Business Organizations

China National Nuclear Corporation (CNNC)
(中国核工业集团公司)

- More than 100 R&D and design institutes and subsidiary companies.
- Total more than 100,000 employees.
- Engineering design – the champion of local designs CNP300, CNP600, CNP1000/CNP1500, CNP1000 lifetime 60 yeas targeting <$US1,300/installed kW.
- Plant construction.
- Uranium exploration and mining.
- Uranium enrichment.
- Fuel fabrication and reprocessing.
- Waste disposal.
- Nuclear components and instrument manufacture.
- An investor in all nuclear plants.
- Designed and built Qinshan units 1-3 and in full control of Qinshan operation.
China Nuclear Engineering & Construction Corporation (CNEC) (中国核工业建设集团公司)

- The largest State owned nuclear power investor.
- The largest nuclear power operating organization.
- 30,000 employees.
- Nuclear power plants – plant site design, survey, project management, material management.
- Nuclear and Civil engineering.
- Defense engineering.
- Other large industrial projects.
6. INFRASTRUCTURE
Major Nuclear Research and Business Organizations

- **Chinese Academy of Sciences (CAS)**
  More than 17 research institutes – directly involved in or dedicated to nuclear fundamental research programs.
  - FBR development.
  - Fusion and hybrid fusion-fission development.

- **Major Universities**
  Tsinghua University.
  Shanghai Jiaotong University.
  Xi’An Jiaotong University.
7. GENERATION IV PROGRAM
Fast Neutron Breeder Reactor

- Fuel efficiency – 60-70%.
- 1960s – the FBR program started with a zero-power reactor.
- 2020 – a full-scale prototype reactor into operation.
- 2035 – FBR technology ready for commercial deployment.
- 2050 beyond – FBRs evolved to be the main nuclear power source.
### 7. GENERATION IV PROGRAM

**Fast Neutron Breeder Reactor (FBR)**

**MAIN DESIGN PARAMETERS OF FAST BREEDER REACTOR**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal Power</strong></td>
<td>65 MW</td>
</tr>
<tr>
<td><strong>Thermal Power</strong></td>
<td>20 MW</td>
</tr>
<tr>
<td><strong>Fuel Type</strong></td>
<td>UO2 (64.4% enriched) Mixed-oxide (MOX)</td>
</tr>
<tr>
<td><strong>Coolant</strong></td>
<td>Sodium</td>
</tr>
<tr>
<td><strong>Core inlet temperature</strong></td>
<td>360°C</td>
</tr>
<tr>
<td><strong>Core outlet temperature</strong></td>
<td>530°C</td>
</tr>
<tr>
<td><strong>Core height</strong></td>
<td>45 cm</td>
</tr>
<tr>
<td><strong>Core diameter</strong></td>
<td>60 cm</td>
</tr>
<tr>
<td><strong>Fuel element linear power (max)</strong></td>
<td>430 W/cm</td>
</tr>
<tr>
<td><strong>Max burn-up (target)</strong></td>
<td>100 MWd/kg -</td>
</tr>
<tr>
<td><strong>Neutron flux</strong></td>
<td>$3.7 \times 10^{15}$ n/cm²·s</td>
</tr>
<tr>
<td><strong>Reactor lifetime</strong></td>
<td>30 years</td>
</tr>
</tbody>
</table>
7. GENERATION IV PROGRAM

Fast Neutron Breeder Reactor

- Experimental reactor (65 MW) under construction
- 2006 - the main vessel passed testing
- 2008 – due to achieve criticality
- 2010 - produce electricity.
7. GENERATION IV PROGRAM

HTR-10

- The PBMR: HTR-10.
  2000 – reached criticality.
  2003 – reached full power and connected to the grid.
- Efficiency – 47%, Inherent passive safety feature.
- Temperature – 700-900°C, 60 years lifetime.
- Cogeneration – power + H2 (or power + other purchases).
- Operational - 2010.
8. FUSION


• China’s largest controlled fusion device.
• Both for fusion and hybrid fusion-fission research.

CAS Southwest Institute of Physics
8. FUSION

• 2002 – HL-2A Tokamak into operation.
• HL-2A – The first divertor Tokamak in China.
8. FUSION

HT-7 Superconducting Tokamak

- Prior to HT-7 Superconducting Tokamak - HT-6B, HT-6M Tokamaks.
- 1994 – completion HT-7 Superconducting Tokamak.
- The first of the kind in China, the fourth device in the world.
- 2004 – HT-7 Plasma achieved 10 million°C in the center for 120 s.
- 2006 - HT-7U full superconducting Tokamak - Construction completed - non-circular section Tokamak.
- HT-7U – The same principle at smaller scale, similar design to ITER.
8. FUSION

Hybrid Fusion-Fission Reactor

- 20 years – Conceptual Design and R & D Activities.
- Subcritical Fusion System.
- Transmuting long-lived radioactive nuclear waste.
- Producing Fuel.

CAS Southwest Institute of Physics
CAS Institute of Plasma Physics
9. OTHER ACCOMPLISHMENTS

Nuclear Submarine

1970 – Launched the China’s first submarine.
The fifth country to have nuclear submarines.
9. OTHER ACCOMPLISHMENTS

Chasuma Phase-I (Unit 1), Pakistan

1991 - Signed the contract (300 MWe).
1993 - Started construction.
2000 - Connected to the grid.
9. OTHER ACCOMPLISHMENTS

Chasuma Phase-II (Unit 2)-Pakistan

2004 - Signed contract (CNNC with PAEC).
2011 – Expected to connect to the grid.
9. OTHER ACCOMPLISHMENTS

Nuclear Heating Reactor (NHR-5)

- Program started in the early 1980s,
- NHR-5 reached full power in 1989.
- A vessel type light water reactor.
- Conducted heat-electricity cogeneration, air-conditioning and desalination.
- A 200 MW Nuclear Heating Reactor (NHR-200) developed.
- The NHR-200 demonstration plant planned to be built as a heat source for seawater desalination.
9. OTHER ACCOMPLISHMENTS

• 1989 – 35 MeV Proton linear accelerator went into service.
• China’s first 35 MeV Proton linear accelerator.
• Mainly for short-lived isotope production for medical applications.
• Research on neutron cancer treatment.

CAS Institute of High Energy Physics
9. OTHER ACCOMPLISHMENTS

The Beijing Electron-Positron Collider

• 1988 - Successfully commissioned and demonstrated.
• Mainly for Physics and material research.

Developed and Constructed at the CAS Institute of High Energy Physics
9. OTHER ACCOMPLISHMENTS

北京正负电子对撞机光荣退役

The Beijing Electron-Positron Collider

• 2004 – BEPC mission completed after 15 years service.
• Currently under refurbishment.
10. OTHER MILESTONES

• 1958 - A 7-MW Heavy Water Research Reactor into Operation
• 1958 - 1.2 m diameter, 12.5 MeV cyclone accelerator went into service.
• 1981 - China's first large-scale self-design and self-made research high-throughput and high-power (125 MW) reactor into operation.
• 1982 - China's first self-designed, self-made proton linear accelerator construction completed at the CAS Institute of High Energy Physics.
• 1983 - Entered IAEA and applied safeguards to nuclear exports to Algeria, Chile, Ghana, Nigeria, Pakistan and Syria.
• 1988 – China’s largest heavy ion physics laboratory equipment - Lanzhou heavy ion cyclotron into operation.
• 1993 – Two free-electron laser devices "SG-1" and BFEL into operation for fundamental and fusion research.
SUMMARY

• A huge demand and potential for nuclear powder.
• Strong government commitment to significantly increase nuclear power capacity.
• Keen on fuel efficient technology due to limited U reserve.
• Engaged in a large range of technologies including Gen I, II and III as well as fuel enrichment and fuel cycle.
• Among the leading edge in technologies of generation IV and fusion reactors, including FBR, HTR, nuclear H2-power cogeneration, Fusion and hybrid fusion-fission reactors.
• Large manpower and large number of organizations involved.
• Technology localization policy: R&D, design & engineering as well as manufacturing and constructions.
ACKNOWLEDGEMENT

• Thanh To – Marketing and Competitive Intelligence, AECL SP
• Martin Nowak - Marketing International, AECL SP
• Xiaolin Wang - Reactor Physics, AECL CRL
• Morgan Brown - Fuel and Fuel Channel Safety, AECL CRL
• George Lim – Safety Review Committee, AECL CRL
Thank You