ENVISION OF NUCLEAR ENERGY AND FUEL CYCLE DEVELOPMENT IN CHINA

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China Institute of Atomic Energy
OUTLINES

● Global nuclear energy development
 ☞ Fukushima nuclear accident and the global nuclear renaissance
 ☞ China’s nuclear power program after Fukushima

● Nuclear fuel cycle options
 ☞ World general trend in fuel cycle for sustainable development
 ☞ China’s efforts to develop FR fuel cycle

● Concluding remarks
Global nuclear energy development

Fukushima nuclear accident and the global nuclear renaissance
Fukushima nuclear accident and the global nuclear renaissance

On March 11, 2011, the super strong earthquake-tsunami in east Japan caused widespread devastation.

Before quake-tsunami

After quake-tsunami
China's Action towards Development of Nuclear Energy System

Fukushima nuclear accident and the global nuclear renaissance

The quake-tsunami then caused disastrous Fukushima nuclear accident
The Fukushima nuclear disaster is really shocking the nuclear industry globally—“Phase out nuke again?”.

☞ Germany has announced to close all the NPPs by 2022.

☞ On June 14, 2011, Italy’s referendum vetoed the government decision to restore the nuclear power.

☞ Japan shut down all the NPPs in June 2011, but later re-opened some units.
However, the Fukushima nuclear accident has not changed the global challenging problems on world population, resources and environment.
Fukushima nuclear accident and the global nuclear renaissance

The current path is far from sustainable development!

☞ The global CO2 emission was 30.6 Bt in 2010, hitting the historic high.

☞ The IPCC warns that by 2050, global GHG emissions must be cut by 70% to avert catastrophic change in our planet’s climate system.
Fukushima nuclear accident and the global nuclear renaissance

Contribution of nuclear energy in C reduction

☞ As we know that the global renaissance of nuclear energy is mainly attributed to its contribution to coping with the global warming.

☞ World 370 GWe NP contributes to the CO₂ reduction of 2.2 Bt/a, constituting some 8% of the global GHG discharge.

☞ In this regard, nuclear power should not be “phased out”, unless the C reduction commitment could be “phased out”.
Fukushima nuclear accident and the global nuclear renaissance

WNA’s expectation of global energy supply
### Fukushima nuclear accident and the global nuclear renaissance

#### Nuclear Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>2011 Nuclear Fuel Share (Percent)</th>
<th>Operating</th>
<th></th>
<th>Under Construction</th>
<th></th>
<th>Planned</th>
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<td>59,218</td>
<td>131²</td>
<td>261²</td>
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(From: NEI (USA) white Paper, July 2012)
Fukushima nuclear accident and the global nuclear renaissance

Global view of nuclear power development

(From: NEI (USA) white Paper, July 2012)
Global nuclear energy development

China’s nuclear power program after Fukushima
China’s nuclear power program after Fukushima

Since 1991, the mainland of China has built 5 nuclear power bases of qinshan, daya bay, lingao, tianwan and Hongyanhe.

Qinshan  Daya bay  Tianwan
China’s nuclear power program after Fukushima

Present status of nuclear power capacity in China (mainland)

<table>
<thead>
<tr>
<th>NPPs</th>
<th>Units</th>
<th>Capacity GWe</th>
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<tr>
<td>In operation</td>
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<td>14.77</td>
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<tr>
<td>Under construction</td>
<td>28</td>
<td>30.54</td>
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Data published up to June 2013
China’s nuclear power program after Fukushima

China's NPPs under construction account for 40% of world total

The NPPs under construction in the world (By the end 2012)
China’s nuclear power program after Fukushima

Present status of nuclear power capacity in China (mainland)
China’s nuclear power program after Fukushima

Later Progress after Fukushima

State Council’s 4 decisions set on March 16, 2011:

- Immediate safety examinations to all nuclear facilities
- Strengthen the safety management of the operational facilities
- Comprehensive review of the nuclear facilities under construction
- Suspend the approval of the new projects
Later Progress after Fukushima

- By the end 2011, General safety examination completed. Results showed that NPPs both in operation and under construction met the requirements of China’s present safety criteria.

- On May 31, 2012, the State Council approved in principle 2 documents:
  - 《Nuclear Safety Review Report》
  - 《Nuclear Safety Program and 2020 Target》
China’s nuclear power program after Fukushima

Later Progress after Fukushima

- On October 24, 2012, the State Council made the decision to re-start the NPP program and approved the documents of:
  - Nuclear Safety Program
  - 《Adjusted Program of medium and Long-Term Development of Nuclear Power (2011-2020)》

- Major points:
  - Safe and high efficient in priority
  - New NPPs must meet the safety criteria of 3rd generation
  - Suspend the inland NPPs construction before 2015
China’s nuclear power program after Fukushima

Later Progress after Fukushima

Planned Installed capacity of NPPs by 2020

<table>
<thead>
<tr>
<th>2020 target</th>
<th>Capacity in operation GWe</th>
<th>Capacity Under construction GWe</th>
<th>Total Capacity GWe</th>
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</thead>
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<td>70</td>
<td>18</td>
<td>88</td>
</tr>
<tr>
<td>After adjustment</td>
<td>58</td>
<td>30</td>
<td>88</td>
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Nuclear fuel cycle options

World general trend in fuel cycle for sustainable development
Sustainability of nuclear fission energy

Two prerequisites for sustainable development of nuclear energy, while keeping safety and economic competitiveness and non-proliferation:

☞ Full utilization of uranium resources
☞ Minimization and safe disposal of nuclear waste
World general trend in fuel cycle for sustainable development

Presently practiced LWR nuclear fuel cycles in the world:

- Once-Through Cycle (OTC)
- PWR Closed Fuel Cycle (CFC)
World general trend in fuel cycle for sustainable development

LWR Once-Through Cycle (OTC)

☞ Simpler

☞ Cheaper

☞ “Prolif. Resist.” in 100 years
World general trend in fuel cycle for sustainable development

LWR Closed Fuel Cycle (CFC)

- Separated Pu
  MOX used in LWR

- Separated U
  Re-enriched and used in LWR
  or stored as reserves for future use in fast reactors
World general trend in fuel cycle for sustainable development

The availability time of the global conventional U resources (1540 t) of the present global nuclear capacity (373 GWe)

<table>
<thead>
<tr>
<th>Fuel cycle case</th>
<th>Availability time years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal reactor OTC</td>
<td>~62</td>
</tr>
<tr>
<td>Thermal reactor CFC</td>
<td>~100</td>
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</tbody>
</table>
World general trend in fuel cycle for sustainable development

The availability time of the global U in OTC case

Source: V Romanello et al., Sustainable Nuclear Fuel Cycles and World Regional Issues, Sustainability 2012, 4
World general trend in fuel cycle for sustainable development

The availability time of the global U in OTC case

![Graph showing the availability time of fuel types over time](image-url)
China's Action towards Development of Nuclear Energy System

World general trend in fuel cycle for sustainable development

The problem of spent fuel accumulation
------A big burden for disposal in long term (2150)

As a consequence of a OTC, a large amount of spent fuel will accumulate worldwide (~500,000 t) in 2150. The spent fuel composition corresponds to roughly 65,000 t of TRU, which contain ca. 50,000 t Pu and ca. 11,000 t MA

Source: V Romanello et al., Sustainable Nuclear Fuel Cycles and World Regional Issues, Sustainability 2012, 4
World general trend in fuel cycle for sustainable development

Source: V Romanello et al., Sustainable Nuclear Fuel Cycles and World Regional Issues, Sustainability 2012, 4
World general trend in fuel cycle for sustainable development

Major results of the recent studies by EU experts

- LWR OTC case is not sustainable;
- No significant differences would result in case of MOX fuels use in PWRs (also non-sustainable);
- World Transition towards Advanced Fuel Cycles (FR fuel cycle) is inevitable.

(Source: V Romanello et al., Sustainable Nuclear Fuel Cycles and World Regional Issues, Sustainability 2012, 4)

These results are in well agreement with that of US initiated G-IV and IAEA supported INPRO programs
With the current efficiency of U in NPPs and at the projected 2012 rate of consumption, the U resources may last up to approximately 100 years, depending on the nuclear power growth rate in the next decades.

Security of supply will be assured for thousands of years when fast neutron reactors are deployed.
World general trend in fuel cycle for sustainable development

SRIA suggested the sustainable NFC in FRs

- With the current efficiency of U in NPPs and at the projected 2012 rate of consumption, the U resources may last up to approximately 100 years, depending on the nuclear power growth rate in the next decades.
- Security of supply will be assured for thousands of years when fast neutron reactors are deployed.
SRIA suggested the sustainable NFC in FRs

- By **multi-recycling** of the nuclear fuel, FBR can increase the U utilization by some **60 times**, thus making **nuclear energy** “**renewable**”.

- By burning (transmutation) MA, FR can reduce the volume and toxicity of hi-level nuclear waste by **2 orders of magnitude**.
World general trend in fuel cycle for sustainable development

SRIA suggested the sustainable NFC in FRs

Advanced NFC in FRs

Breeder--max. use of U

Burner---min. of waste

Sustainable nuclear energy
China's Action towards Development of Nuclear Energy System

World general trend in fuel cycle for sustainable development

SRIA suggested the sustainable NFC in FRs of U in NPPs and at the projected 2012 rate of consumption, the U resources may last up to approximately 100 years, depending on the nuclear power growth rate in the next decades.

(Based on the IIASA-WEC C2 Scenario)

Identified Resources: 4.74 M tons (less than 130 US$/$kgU = 50 $/lb U₃O₈)

(Based on the IIASA-WEC C2 Scenario)
FBR commercialization time announced by some countries

<table>
<thead>
<tr>
<th>Country</th>
<th>India</th>
<th>Russia</th>
<th>France</th>
<th>Japan</th>
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<tr>
<td>Time</td>
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<td>2025</td>
<td>2040</td>
<td>2050</td>
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Advanced fuel cycle---- the sustainable way

The Asia transition from PWR to FR cycle predicted by EU experts

Source: V Romanello et al., Sustainable Nuclear Fuel Cycles and World Regional Issues, Sustainability 2012, 4
Conclusions of this section

- Both LWR OTC and CFC are not sustainable.
- The FR FC is sustainable for nuclear fission energy.
- For this reason, the major nuclear energy countries have been working on R&D of CFC technologies for several decades.
Nuclear fuel cycle options
China’s efforts
to develop FR fuel cycle
China’s efforts to develop FR fuel cycle

Our starting point

As an important member of the IAEA, China’s nuclear energy and fuel cycle option should be geared to the general trend of the international development.
China’s efforts to develop FR fuel cycle

Perspective of China’s nuclear energy development

● To ensure the energy security and environmental safety, China’s nuclear energy will be expanded to some 150-200 GWe by 2030 and may possibly be 400-500 GWe after 2050.

● If China deploys PWRs solely, it would consume 4-5 Mt natural U, almost all U reserves of the world at the cost of 130 $/kg, to support only 60 years.
China’s efforts to develop FR fuel cycle

Perspective of China’s nuclear energy development

- Obviously, such situation is beyond our imagination and thus not sustainable.

- This is why China should follow the world trend to develop FBR fuel cycle and transit from present PWR to future FR fuel cycle.
China’s efforts to develop FR fuel cycle

Perspective of China’s nuclear energy

Transition from present PWR to future FR fuel cycle
China’s efforts to develop FR fuel cycle

Present status of the backend fuel cycle in China

The **back end** of the fuel cycle, essentially the FR fuel cycle, includes:

- PWR SF reprocessing
- FBR fuel fabrication
- FBR SF reprocessing
- Partitioning-transmutation
- HLW treatment and disposal
China’s efforts to develop FR fuel cycle

Present status of the backend fuel cycle in China

- It must be pointed out that presently China’s nuclear fuel technology lags far behind the world advanced level, even behind India for many years.

- Up to now, China does not have the industrial capability in the backend of fuel cycle.
China’s efforts to develop FR fuel cycle

Reprocessing

- The **pilot plant of spent fuel reprocessing** with a testing task of 50 tHM has completed hot test in December 2010, which is an important progress towards the commercialization of reprocessing.
- This plant is under improvement and needs some 3 years to fulfill the task of reprocessing 50 tHM spent fuel.
Reprocessing

● R&D on advanced reprocessing
   ⛩ Improved Purex process using salt-free reagents has completed the simulated experiments and hot tests will be carried out in coming years.
   ⛩ HLLW partitioning with TRPO has completed the hot tests and engineering demo is planned.

● R&D on dry reprocessing of FR spent fuel
  This work is at the initial stage in China.
China’s efforts to develop FR fuel cycle

MOX fuel fabrication

- R&D on MOX pellets and design of fuel assemblies are under way
- A fabrication laboratory with the capacity of 500 kg/a MOX (45% Pu) has been built for feeding CEFR by 2018
China’s efforts to develop FR fuel cycle

Facing the backward situation in nuclear fuel cycle technologies, China needs to strengthen the R&D on reprocessing and FR fuel fabrication, and to close the FR cycle step by step.
China’s efforts to develop FR fuel cycle

Envision of near-term goal of FR fuel cycle in China (Before 2020)

- Using pilot reprocessing plant, 500kg/a MOX lab, CEFR as the platforms, to half close the FR cycle at the experimental level.
China’s efforts to develop FR fuel cycle

Envision of mid-term goal of FR fuel cycle in China (Before 2030)

- Using 200 t/a reprocessing plant, 4 t/a MOX plant, CDFR as the platforms, to half close the FR cycle at the engineering level.

- More time needed for R&D of FR spent fuel reprocessing.

[Diagram showing the FR fuel cycle with PWR SP Rep 200 t/a Plant, 4 t/a MOX Plant, and CDFR.]
It is my understanding that China needs at least another 3 decades’ efforts before the commercialization of FR energy system.

Our present progress is only the first step of our new Long March.
Concluding Remarks

● The global nuclear energy development has stepped out of the shadow of Fukushima accident.

● Advanced nuclear fuel cycle, or FR cycle, is the sustainable way of nuclear fission energy. Such understanding is becoming the consensus of the world nuclear community.

● China has a big nuclear energy program and must be geared to the international trends to choose the advanced fuel cycle option.
THANK YOU!

谢谢！