Nuclear Energy and Nuclear Fuel Cycle Policy Options after the Fukushima Accident

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Honolulu, Hawaii,
February 26, 2014
Tatsujiro Suzuki
Vice Chairman, Japan Atomic Energy Commission

Note: The views expressed here are of my own and do not necessarily reflect those of the JAEC nor the government.
Summary

• After 3/11, priority of nuclear energy policy has changed significantly. Top priority should be on measures dealing with the Fukushima Daiichi nuclear power plant decommissioning and securing welfare of people affected by the accident.

• Given the uncertainty in future directions of nuclear energy, priority should be on the necessary measures regardless of future of nuclear energy policy.

• Based on the assessments, on economics, safety, and proliferation risks etc., made by the subcommittee, JAEC issued a policy statement that nuclear fuel cycle policy needs to be more flexible in order to cope with future uncertainty.

• Specifically, priority should be on the following measures.
  – Expansion of spent fuel storage (especially dry cask storage)
  – Measures to enable “direct disposal” of spent fuel
  – Plutonium stockpile management
The Japan Atomic Energy Commission is set up in the Cabinet Office and has five commissioners. Its mission is to conduct planning, deliberations, and decision-making regarding basic policy for research, development, and utilization of nuclear energy, including the formulation of the Framework for Nuclear Energy Policy except matters related to nuclear safety regulation. When the JAEC deems it necessary as a part of its assigned mandate, JAEC can recommend and demand reports of the head of relevant administrative organization through the Prime Minister.

Members: 5 (appointed by the Prime Minister with the consent of the House of Representatives and House of Councilors)
Role of JAEC (??)

- A small tag-boat for a giant Titanic? –
Role of AEC should be fundamentally changed from basic policy maker as a promoter of nuclear energy to act as an advisor for better governance of nuclear energy, while maintaining its neutral positions. Its activities should focus on the following areas:

1. Assuring peaceful use of nuclear energy and non-proliferation
2. Management and disposal of radioactive waste
3. Other important matters (such as decommissioning of Fukushima nuclear power plants)

Fukushima Daiichi Decommissioning and Restoring life in Fukushima area
Struggling with contaminated water...during the recent typhoon (Sept. 15, 2013)

"I think the current situation is that it is not under control," by a TEPCO official.

-Fukushima ‘not under control’ – TEPCO official refutes PM's assurances, Reuter, Sept. 13, 2013


Mid-Long Term Roadmap for Fukushima Dai-ichi

**Targets under the Initial Roadmap**

- December 2011 (Roadmap established)
- **December 2013**
  - **Phase 1**
    - Period up to the commencement of the removal of the fuel from the spent fuel pool (within 2 years)
  - **Phase 2**
    - Period up to the commencement of the removal of the fuel debris (within 10 years)
  - **Phase 3**
    - Period up to the completion of decommissioning measures (30 to 40 years in the future)

- **30 to 40 years in the future**

**Plan under the Revised Roadmap (example: Unit 2)**

- **Existing reactor building**
- **Roadside crane**
- **Fuel Handling Machine (FHM)**
- **Upper container**
- **Separate container**

**<Plan 1>**
- When the existing reactor building can be decontaminated and the FHM can be restored

**<Plan 2>**
- When the reactor building has sufficient seismic resistance for a container to be constructed on its upper level

**<Plan 3>**
- When the reactor building lacks sufficient seismic resistance, necessitating the construction of a separate container

**First half of FY2020**
- One-and-a-half years earlier than the initial plan

**Commencement of the removal of the fuel debris**

**First half of FY2021**
- 6 months earlier than the initial plan

**Commencement of the removal of the fuel debris**

**First half of FY2024**

**Commencement of the removal of the fuel debris**

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Evacuation Area Amended (13/08/08)

(2012/04/29) Amended
(12/12/10) Amended
(13/04/01) Amended
(13/08/08) Amended

Tomioka

http://www.kantei.go.jp/saigai/pdf/20130307gainenzu.pdf,
Cherry blossom in Tomioka Town
(10 km from Fukushima Daiichi, 2012/04)

http://www.asahi.com/special/10005/images/TKY201204190192.jpg

http://img.47news.jp/PN/201204/PN2012041901001125.--.--.Cl0003.jpg
Compared with the Chernobyl accident

Restoring Public Trust in Nuclear Safety and Energy Policy
Goal of Power Production Mix in 2030 Before 2011/3/11

Share of nuclear power

- Result of 2005: 30.9%
- Result of 2007: 25.8%
- Maximum nuclear exp. in 2020: 41.5%
- Maximum nuclear exp. in 2030: 48.7%

Source: Institute of Energy Economics, March 2010
What is your opinion about nuclear power in Japan?

<table>
<thead>
<tr>
<th>Option</th>
<th>2013 Year 3</th>
<th>2012 Year 3</th>
<th>2011 Year 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediately shutdown</td>
<td>30.7%</td>
<td>19.8%</td>
<td>13.3%</td>
</tr>
<tr>
<td>Gradually phase-out</td>
<td>54.1%</td>
<td>63.0%</td>
<td>66.4%</td>
</tr>
<tr>
<td>Status quo</td>
<td>9.8%</td>
<td>13.9%</td>
<td>16.5%</td>
</tr>
<tr>
<td>Gradually increase</td>
<td>3.1%</td>
<td>1.6%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Gradually increase</td>
<td>1.3%</td>
<td>0.9%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Total Dependence on Nuclear Energy</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Impact of Shutdown of Nuclear Power from FY 2010 to FY 2012

Share of nuclear power down from 31% to 2%

3.1 trillion yen extra expenses due to loss of nuclear power

Japan’s CO2 emission increased by 70 MT or 5.8% from 2011


Yen/kWh

2004年試算

5.9円

資本費 +0.2円
運転維持費 +1.0円
核燃料サイクル ▲0.1円
追加的安全対策 +0.2円

Costs associated with accident

8.9 yen/kWh if total accident costs is 6 trill yen.
It will increase 0.1 yen/kWh
If total accident costs Increase 1 trillion yen.

8.9円（下限）

Capital cost
O&M
Fuel cycle
Additional cost

5.9円

政策経費 +1.1円

8.9円

+0.5円以上

Subsidaries

2011

出所:コスト等検証委員会報告書、2011年12月19日
Nuclear power can be competitive, but social costs can be high…
Reflecting on the accident at Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station, under the Nuclear Regulation Authority, we will foster a new culture of safety that will uncompromisingly enhance the degree of safety. After doing so we will restart nuclear power plants where safety has been confirmed.

We will promote the introduction of energy conservation and renewable energies to the greatest possible extent to reduce our degree of dependency on nuclear power as much as possible. At the same time, we will begin a fundamental reform of the electric system.

http://www.kantei.go.jp/foreign/96_abe/statement/201302/28sihefusihousin_e.html
Recommendations to the Energy Basic Plan (Draft)  
by METI’s Advisory Council on Energy  
- For Nuclear Energy Policy (2013/12/06) 

- We continue to use nuclear energy as an important base-load energy source to support stable energy supply.
- We reduce dependence on nuclear energy as much as possible by expanding renewable energy, energy efficiency and more efficient fossil power plants.
- Under this basic policy, considering the constraints of energy resource situations, we maintain the necessary level of nuclear power from the viewpoints of energy supply stability, cost reduction, climate change, human resources to maintain the safety.

http://www.enecho.meti.go.jp/info/committee/kihonseisaku/12th/12th1-2.pdf
Recommendations to the Energy Basic Plan (Draft) 
by METI’s Advisory Council on Energy 
- For Nuclear Energy Policy (2013/12/06)

(1) Measures to recover and revitalize Fukushima
(2) Enhance safety constantly and establish environment for stable nuclear business operations
(3) Steady progress in measures without delay
   ① Comprehensive and enhanced measures to deal with spent nuclear fuel
      • Strengthen measures for final disposal of HLW
      • Expansion of spent fuel storage capacity
      • R&D on reduction of toxicity/volume of radioactive waste
   ② Steady progress in nuclear fuel cycle
      • Important to increase flexibility of nuclear fuel cycle

(4) Building confidence with citizens, local governments and international society
   ① Public communication after Fukushima accident
   ② Building confidence with local siting community
   ③ Contribution to peaceful use of nuclear energy in the world and non-proliferation

http://www.enecho.meti.go.jp/info/committee/kihonseisaku/12th/12th1-2.pdf
Nuclear Fuel Cycle Options
Major Findings of JAEC subcommittee on nuclear power and fuel cycle (12/06/05)

• For the next 20~30 years, “MOX recycling” and “Once-through” fuel cycle are the only commercially available options.
  – “Once-through” is more desirable from economic and nuclear proliferation/security standpoints, but “MOX recycling” is more desirable from resource efficiency standpoint.
  – No significant difference in terms of safety and waste management.

## Cost Comparison of Nuclear Fuel Cycle Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Yen/kWh</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Reprocessing</td>
<td>2.1</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Current Model*</td>
<td>2.2</td>
<td>1.8</td>
<td>1.4</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Direct Disposal</td>
<td>1.4</td>
<td>1.1</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

### Breakdown of Costs

- **Front End**
  - U fuel: 0.6, 0.8, 0.9
  - MOX fuel: 0.7, 0.8, 0.9
- **Back End**
  - Reprocessing: 0.1, 0.1, 0.1
  - Storage: 0.5, 0.5, 0.5
  - HLW disposal: 0.1, 0.1, 0.1
  - Direct disposal: 0.1, 0.1, 0.1

### Notes

*50% immediate reprocessing and 50% reprocessing after long term storage*

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**Source:** National Policy Unit, Energy and Environmental Council, Cost etc. Verification Committee.

Fuel Cycle Economics in Variation of Options (Summary)

- For all nuclear share option, **total expense of F.C. option 3 is less than the other F.C. options.**
- As for F.C. option 3, SF stored in Aomori pref. may have to be sent back and under the worst case, **nuclear power operation could be suspended if new SF storage capacity is not available.**

<table>
<thead>
<tr>
<th>Total Expense of Fuel Cycle (Unit: trillion yen)</th>
<th>&lt;Discount rate: 0 %&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F.C. Option 1</strong></td>
<td><strong>F.C. Option 2</strong></td>
</tr>
<tr>
<td>Total reprocessing</td>
<td>Coexistence of</td>
</tr>
<tr>
<td></td>
<td>reprocessing/disposal</td>
</tr>
<tr>
<td>Nuclear Share Option I: 35 %</td>
<td>18.4</td>
</tr>
<tr>
<td>Nuclear Share Option II: 20 %</td>
<td>15.4</td>
</tr>
<tr>
<td>Nuclear Share Option III: 15 %</td>
<td>14.4</td>
</tr>
<tr>
<td>Nuclear Share Option IV: 0 %</td>
<td>—</td>
</tr>
</tbody>
</table>

Assessment of Nuclear Fuel Cycle Policy Options by Subcommittee (June, 2012)

• “All reprocessing” option: Most desirable when nuclear power will expand or stay as it is

• “Co-existing of reprocessing/direct disposal” option: Most desirable when future of nuclear energy is uncertain

• “All direct disposal” option: Most desirable when nuclear energy will be phased out

As recommended by the technical subcommittee, regardless of the policy choice, it is vital to build a system ready to cope with future policy changes.

http://www.aec.go.jp/jicst/NC/about/kettei/kettei120621_2.pdf
Three types of spent fuel storage capacity
(As of September 2013, total of 17,335 tons are in storage)

At-reactor storage
Storage capacity: 20,640 tU/17 sites (as of Sept. 2013, 14,340tons ~70% full)
On-site dry cask storage is not allowed by local governments (Fukushima-1 & Tokai-2 was allowed).

If Rokkasho was cancelled...

Rokkasho reprocessing plant
Storage capacity: 3,000tU
(storage 2,945 tU as of Sept. 2013)
Construction cost: \2.14Trillion
Commission date: not known

Mutsu Interim storage site
Dry Cask storage type
Capacity: totally 5,000 tU
1st 3,000 tU, add 2,000tU in future
Operation: October 2013 (postponed)
(Status: under construction)
Construction cost: \0.1Trillion
(including dry casks)
Dry Cask Storage at Fukushima Daiichi (after 3/11)

http://photo.tepco.co.jp/library/110909_2/110909_69.jpg
Basic Policy for FY 2014 Nuclear Energy Budget (2013/07/17)

• On nuclear fuel cycle policy, there are measures which are necessary regardless of future of nuclear energy policy. Parties should promote such measures with increased flexibility as JAEC decision on June 21, 2013.

• Especially, government should take more active leadership in expanding storage capacity of spent fuel, measures to enable direct disposal and final disposal of high-level radioactive waste.

• Especially, on plutonium management, principle of “no plutonium surplus policy” should be strictly followed, with enhanced transparency and more persuasive programs than the current measures.

http://www.aec.go.jp/jicst/NC/about/kettei/kettei130717.pdf
JAEC’s “No Pu surplus policy”

- Since 1991, Japan stick to a principle of “no plutonium surplus policy”, i.e. Japan does not have any plutonium which does not have specific purposes to use.
- In August 2003, JAEC announced its new guideline for plutonium management preparing for commissioning of the first commercial reprocessing plant.
  - Utilities are expected to submit its plutonium usage plan annually before separation of plutonium.

But, Japan now has 44 tons (35 tons in Europe, 9 tons in Japan) of stockpile.

“Plutonium stockpile should be reduced regardless of fuel cycle options chosen in the future”

## Pu Use Plan for Rokkasho (FY2010)

<table>
<thead>
<tr>
<th>Region</th>
<th>Pu stock (End of FY 2009)</th>
<th>Pu recovered (FY2010)</th>
<th>Pu stock (End of FY2010)</th>
<th>Reactors for Pu use</th>
<th>Pu use per year</th>
<th>Planned period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hokkaido</td>
<td>72kgfis</td>
<td>0</td>
<td>72kgfis</td>
<td>Tomari#3</td>
<td>0.2tonfis/y</td>
<td>FY2015~</td>
</tr>
<tr>
<td>Tohoku</td>
<td>78</td>
<td>0</td>
<td>78</td>
<td>Onagawa#3</td>
<td>0.2</td>
<td>FY2015~</td>
</tr>
<tr>
<td>TEPCO</td>
<td>748</td>
<td>0</td>
<td>748</td>
<td>3～4 unit include Fukushima-1#3 (planned)</td>
<td>0.9~1.6</td>
<td>FY2015~</td>
</tr>
<tr>
<td>Chubu</td>
<td>182</td>
<td>0</td>
<td>18</td>
<td>Hamaoka#4</td>
<td>0.4</td>
<td>FY2015~</td>
</tr>
<tr>
<td>Hokuriku</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>Shika #1</td>
<td>0.1</td>
<td>FY2015~</td>
</tr>
<tr>
<td>Kansai</td>
<td>556</td>
<td>0</td>
<td>556</td>
<td>Takahama#3,4 1～2 unit in Ohi</td>
<td>1.1~1.4</td>
<td>FY2015~</td>
</tr>
<tr>
<td>Chugoku</td>
<td>84</td>
<td>0</td>
<td>84</td>
<td>Shimane#2</td>
<td>0.2</td>
<td>FY2015~</td>
</tr>
<tr>
<td>Shikoku</td>
<td>133</td>
<td>0</td>
<td>133</td>
<td>Ikata #3</td>
<td>0.4</td>
<td>FY2015~</td>
</tr>
<tr>
<td>Kyushu</td>
<td>315</td>
<td>0</td>
<td>315</td>
<td>Genkai #3</td>
<td>0.4</td>
<td>FY2015~</td>
</tr>
<tr>
<td>JAPCO</td>
<td>140</td>
<td>0</td>
<td>140</td>
<td>Tsuruga#2. Tokai#2</td>
<td>0.5</td>
<td>FY2015~</td>
</tr>
<tr>
<td>J-Power</td>
<td>(purchase from others)</td>
<td></td>
<td></td>
<td>Ohma</td>
<td>1.1</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,317</td>
<td>0</td>
<td>2,317</td>
<td>--</td>
<td>5.5~6.5</td>
<td>--</td>
</tr>
</tbody>
</table>

# Plutonium Stockpile in Japan (as of the end of 2012)

<table>
<thead>
<tr>
<th>Stock in Japan (Pu total)</th>
<th>2012 (kg)</th>
<th>2011 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reprocessing Plants</td>
<td>4,363</td>
<td>4,364</td>
</tr>
<tr>
<td>MOX Fuel Plant</td>
<td>3,364</td>
<td>3,363</td>
</tr>
<tr>
<td>Stored at Reactors</td>
<td>1,568</td>
<td>1,568</td>
</tr>
<tr>
<td><strong>Sub-total (Pu fissile)</strong></td>
<td><strong>9,295 (6,315)</strong></td>
<td><strong>9,295 (6,316)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stocks in Europe (Pu total)</th>
<th>2012 (kg)</th>
<th>2011 (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>17,052</td>
<td>17,028</td>
</tr>
<tr>
<td>France</td>
<td>17,895</td>
<td>17,931</td>
</tr>
<tr>
<td><strong>Sub-total :Pu total(Pu fissile)</strong></td>
<td><strong>34,946 (23,277)</strong></td>
<td><strong>34,959(23,308)</strong></td>
</tr>
<tr>
<td><strong>Total (Pu fissile)</strong></td>
<td><strong>44,241 (29,592)</strong></td>
<td><strong>44,254 (29,624)</strong></td>
</tr>
</tbody>
</table>

Global Civilian Plutonium Stockpile (2011)
- Reprocessing has international security implications -

Japan’s Plutonium Stockpile

“On nuclear security, Japan and the United States committed to continue to strengthen the nuclear security posture of both countries and to fundamentally reduce the threat that terrorists could acquire nuclear material. Key steps towards these goals include the following:

– Reducing the quantities and attractiveness of weapons-usable nuclear material;”


1. **Demand comes first**: Reprocessing should take place only when plutonium demand (use) is specified. In order to achieve this goal, spent fuel storage capacity must be expanded.

2. **Stockpile reduction**: Matching demand/supply is not good enough. Existing stockpile should be reduced before further reprocessing.

3. **Flexible plan**: Current Pu use plan (MOX recycling in 16~18 units) is no longer certain. Other options (Pu ownership transfer, disposition as waste etc.) need to be pursued. With minimizing cost, transportation and time required to dispose.
REFERENCE
ライフサイクル分析による放射性リスク

核燃料サイクルの主要工程毎の被ばく量概算値について

<table>
<thead>
<tr>
<th>核燃料サイクル工程</th>
<th>操業後500年間にわたるヨーロッパの一般公衆の集団被ばく線量 (manSv/GWe-year)</th>
<th>作業従事者の集団被ばく線量 (manSv/GWe-year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>一次通過 (One-through)</td>
<td>環境 (Recycle)</td>
</tr>
<tr>
<td>採掘、精錬</td>
<td>1</td>
<td>0.79 (1)</td>
</tr>
<tr>
<td>転換、濃縮</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>燃料成形加工</td>
<td>0.0009 (4)</td>
<td>0.0007 (3)</td>
</tr>
<tr>
<td>発電</td>
<td>0.65 (6)</td>
<td>0.65 (6)</td>
</tr>
<tr>
<td>再処理、ガラス固化、中間貯蔵</td>
<td>0</td>
<td>1.534 (8)</td>
</tr>
<tr>
<td>合計</td>
<td>1.65</td>
<td>2.97</td>
</tr>
</tbody>
</table>

注釈
(1) 天然ウラン必要量に基づいて算出。作業従事者の線量はUNSCEAR88による。
(2) 燃料成形加工による影響に合算した。
(3) UO₂とMOX燃料の重量(21.1t, 5.5t)で重み付けして算出。
(4) 一般公衆：解析結果: Romans 3.21×10⁻³, Melox 2.51×10⁻³。
(5) 作業従事者: Romans 6.57×10⁻³, Melox 4.3×10⁻¹。
(6) 一般公衆: 海岸 0.54, 内陸 0.65。
(7) 作業従事者: フランス 900MW(e)プラントの平均。
(8) 一般公衆: サイトを特定しない一般的な評価。
(9) 作業従事者: La Hagueにおけるデータ。

出典:
Potential Hazard of HLW by form

Direct disposal

Vitrified waste from LWR Reprocessing

Vitrified waste from FR Reprocessing

(注1) 高レベル放射性廃棄物と人間との間の障壁は考慮されておらず、高レベル放射性廃棄物の実際の危険性ではなく、潜在的な有害度（経口摂取による年摂取限度で規格化）を示している。使用済燃料取り出し直後の潜在的影響を1とした相対値。

出典: 原子力委員会 原子力政策大綱（平成17年）を基に編集

2012/3/1

原子力発電・核燃料サイクル技術等検討小委員会（第9回）

Potential Exposure Risk from HLW

"What if" case studies in Switzerland assuming 100 times speed of underground flow

スイスの解析例，"what if"ケースとして，地下水の流量をリファレンスケースの100倍と仮定した場合の放射線量

直接処分の場合（左上図）及び再処理を行った場合（右上・右下図）のいずれも，廃棄物からの被ばく線量は，諸外国で提案されている安全基準（0.1〜0.3mSv/年）に比べて十分低い


2012/3/1 原子力発電・核燃料サイクル技術等検討小委員会（第9回）