I. Nuclear Power – Current Status

Nuclear Power Capacity in Japan

<table>
<thead>
<tr>
<th>LWRs in Operation</th>
<th>Number of Units</th>
<th>Generating Capacity (MWe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurized Water Reactors</td>
<td>23</td>
<td>19,366</td>
</tr>
<tr>
<td>Boiling Water Reactors</td>
<td>27</td>
<td>23,664</td>
</tr>
<tr>
<td>Advanced BWRs</td>
<td>2</td>
<td>2,712</td>
</tr>
<tr>
<td>Total</td>
<td>52</td>
<td>45,742</td>
</tr>
<tr>
<td>LWRs under Construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiling Water Reactors</td>
<td>1</td>
<td>1,100</td>
</tr>
<tr>
<td>Advanced BWRs</td>
<td>2</td>
<td>2,738</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>3,838</td>
</tr>
<tr>
<td>Advanced Thermal Reactor in Operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fugen (Prototype)</td>
<td>1</td>
<td>165</td>
</tr>
<tr>
<td>Fast Breeder Reactor under Construction</td>
<td></td>
<td>280</td>
</tr>
</tbody>
</table>
Distribution of Nuclear Power Stations

Growth of Nuclear Power Capacity
Electric Power Generation in Japan

<table>
<thead>
<tr>
<th>Year 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>TWh / Year</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

- Nuclear: 38%
- Coal: 12%
- LNG: 32%
- Hydro: 9%
- Oil: 8%

(By 9 Utilities)

Technical Subjects for Future Development

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Time Range</th>
<th>Technical Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement of Safety</td>
<td>Short</td>
<td>Passive Safety, Higher Reliability of Equipments / Systems</td>
</tr>
<tr>
<td>Reduction of Generation Costs</td>
<td>Short</td>
<td>Simplification of Systems, Higher Fuel Burn-up</td>
</tr>
<tr>
<td>Effective Use of Plutonium</td>
<td>Short - Long</td>
<td>From Burning to Breeding, Backup Strategy for FBR Development</td>
</tr>
<tr>
<td>Disposal of High Level Wastes</td>
<td>Mid - Long</td>
<td>Transmutation or Recycle of Minor Actinides</td>
</tr>
<tr>
<td>Expansion of Application</td>
<td>Long</td>
<td>Hydrogen Production, District Heating, Industry Process Heat</td>
</tr>
<tr>
<td>Assure Fuel Resources</td>
<td>Long</td>
<td>Development of Breeders, Uranium from Seawater, Thorium</td>
</tr>
</tbody>
</table>
II. Assessment of Nuclear Energy Systems

Analytical Tools and Database

- Energy-Economy-Environment Analysis
- Nuclear Fuel Cycle Analysis
- Cost-Benefit-Risk Analysis
- Statistical Database
- Technology Database

Future Role of Nuclear Energy

Strategy of Nuclear Energy Development

Analysis of Power Reactors and Fuel Cycle Systems

Analytical Tools
- Long-Term Simulation Model
- Optimization Model
- Cost Assessment Model

Reactor Types
- Reduc. Moder. Water Reactors
- Small LWRs
- Accelerator Driven Systems

Subjects
- Develop. of New Reactor
- Effective Pu Utilization
- Waste Management

Criteria of Evaluation
- Resource
- Economics
- Environment

Outputs
- Long-Term Outlook
- Role of New Tech.
- R&D Issues

- Non Proliferation
- Social Acceptance

- R&D Planning
- Long-Term Strategy
1. Study on Effective Plutonium Utilization

Plutonium Recycling in Water Cooled Reactors

Example of RMWR Designs

Entire Reactor Core
- Electric Output: 1,356 MWe
- Number of Fuel Assemblies: 900
- Number of Control Rods: 283
- Outer Diameter: 7,600 mm
- Pitch of Fuel Rod: 1.3 mm
- Outer Diameter of Fuel Rod: 13.7 mm

Fuel Assembly
- Control Rods
- Fuel Rods
- Channel Box
- UO₂-PuO₂ Fuel
- UO₂ Blanket
- Diameter: 228 mm
Simulation of Nuclear Fuel Cycle Systems

Nuclear Power Capacity in RMWR Scenario

GWe

Year

2000 2050 2100 2150 2200

LWR (Enriched Uranium)

LWR (Plutonium)

RMWR (BR=1.06)

Nuclear Power Capacity in FBR Scenario

GWe

Year

2000 2050 2100 2150 2200

LWR (Enriched Uranium)

LWR (Plutonium)

FBR (BR=1.2)
**Consumption of Natural Uranium**

- **LWR (No Recycling of Plutonium)**
- **LWR (Maximum Plutonium Recycling)**
- **LWR + RMWR (2020 -)**
- **LWR + FBR (2050 -)**

**Electricity Generation Costs**

- Next Generation LWR with Enriched Uranium
  - Conventional Uranium
  - Seawater Uranium
- RMWR (Reprocessing Cost High*)
  - 45 GWD/t
  - 70 GWD/t
- RMWR (Reprocessing Cost Low**)  
  - 45 GWD/t
  - 70 GWD/t

- Increase Fuel Burup
- Reduce Reprocessing Cost

* RMWR reproces. cost = two times UO2 reproces. cost
** RMWR reproces. cost = UO2 reproces. cost
2. Study on Impacts by Nuclear Phase-out
Development of an Energy–Economy Model

Nuclear Phase-out

MARKAL Model
Adaptation of Energy
- Technology Mix
- Electricity vs Fuel
- Conservation

Macro-Economy Model
More Imports of Fossil Fuel
Utilization of High Cost Alternatives
Income Transfer to Overseas
Lower Productivity of Electric Utilities
Economic Adaptation - Final Demand - Inputs to Industries
Loss of Gross Domestic Products

Reduction in Utility

Basic Structure of the Energy-Economy Model

Labor Population
Labor Service
Capital Service
Capital Stock
Income
Final Demand
Consumption
Govern. Consum.
Export
Non-Energy Import
Energy Import
Investment
Removal of Stock
Macro Economy Model
Energy System Cost
Income
Domestic Production
Energy Import
Energy Service Demand
MARKAL Energy Model
Maximize "Discounted Utility - Energy System Cost"

Endogenous Variables
Exogenous Variables
**Structure of the Macroeconomic Model**

**Removal rate** $k_{dep}(i,t)$ is approximately determined by $k_{dep}(j,t)$ and industry distribution of capital good $i$ at the base year.

**Capital Stock of Industry $j$**
- $k_{dep}(j,t)$
- $k_{dep}(i,t)$
- $k_{sindex}(j,t)$

**Final Demand**
- $GDP_i(t)$
- $Y_i(t)$

**Intermediate Demand**
- $X_i(j,t)$

**Labor Service**
- $KSER_{i}(j,t)$
- $LYS_{i}(j,t)$

**Utility**
- $CL_i(t)$

**Laborers by Industry**
- $L_i(t)$

**Final Demand**
- $Y_i(t)$

**Intermediate Demand**
- $X_i(j,t)$

**Domestic Production**
- $Y_i(t)$

**Energy Service Demand in MARKAL**
- $ED(t) = (ED_0(t)/Y_0(t)) \times Y(t)$
- $Y(t)$ is GDP or Industry Production
- $ED_0$ and $Y_0$ are for the reference case

**Imports in Economy Model**
- $IM('Mining') = \text{Import Coef.} \times \text{Production of Material Industry}$
- $R(t) \times \text{Energy Imports (from MARKAL)}$
- $IM('Oil Prod.') = (1-R(t)) \times \text{Energy Imports (from MARKAL)}$
- $R(t)$ is currently fixed to 0.78.

**Objective Function**
- $\text{Obj} = U - EC$
- $U$: Final Consumption
- $EC$: Energy System Cost

Note: The increase of $U$ by one unit is not conceptually identical with the decrease of $EC$ by one unit. Therefore, the linked model should be used within the range of GDP increases that satisfies the condition ‘unit increase of $U$ > unit decrease of $EC$’.
Procedures of Analysis

1. Establishment of Energy Scenario
   - Basic Assumptions – GDP, Energy Service Demand, Fuel Prices
   - Optimum Energy Scenario by MARKAL

2. Establishment of Reference Energy-Economy Scenario
   - Determine Economic Parameters to Meet Assumed Economic Growth
     (Total Factor Productivity, Flexibility of K-L Substitution, etc.)

3. Investigate the Impacts by Nuclear Phase-out
   - Optimize the Energy-Economy Systems without Nuclear Energy
   - Analyze Sensitivity with Respect to Potential Flexibility of Economy
     (Goods/Services Mix of Final Consumption, Intermediate Inputs, and Investment)
   - Analyze Sensitivity to Other Assumptions (e.g. CO₂ Emission Caps)

Results of Analysis

To be presented at the next ETSAP Workshop.