NUCLEAR POWER TODAY

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GOALS

• To Understand the Situation and Prospects of the Nuclear Power Enterprise Within the Overall Energy Context
  – Domestically
  – Internationally
NUCLEAR POWER TECHNOLOGIES

GOALS OF NUCLEAR POWER DISCUSSION: To Answer the Following Questions

• Who used nuclear power today?
  Answer: Most industrialized countries.

• Who is likely to use nuclear power in the future?
  Answer: East Asian and developing countries, countries wanting energy supply diversity.

• What are the important nuclear power technologies
  – Future? Answer: Maybe LWRs near term, gas-cooled reactors medium term, breeder reactors long term.

• How could nuclear power relieve global warming?
  Answer: Most likely with large-scale, high-temperature breeder reactors.

• What are the future prospects for nuclear power?
  Answer: That depends upon how concerned people are about the problems of other energy technologies.
TYPES OF STEAM-ELECTRIC GENERATING PLANTS

Fossil fuel, Nuclear BWR, Nuclear PWR, Nuclear LMFBR

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TYPES OF STEAM-ELECTRIC GENERATING PLANTS

Four diagrams removed for copyright reasons.
Fossil fuel, Nuclear BWR, Nuclear PWR, Nuclear LMFBR
NUCLEAR POWER STATUS WORLDWIDE

- About 440 Reactors Operating
- Source of 17% of Worldwide Electricity
- Source of 25% of Electricity in Industrial Countries
- Source of 20% of United States Electricity (103 Reactors)
- Effective New Plant Moratoria in Most Industrialized Countries
- Japan, France Ordering a New Plant Every Few Years
- China, Korea, Taiwan Have Been Ordering Frequently
  Some annual electricity demand growth rates near 10% until recently
- Finland Is Ordering a New Plant
### SUMMARY OF TYPES OF POWER REACTORS USED WORLDWIDE

<table>
<thead>
<tr>
<th>Type</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Coolant Temperature (°C)</th>
<th>Deployment</th>
<th>Current Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressurized Water (PWR)</td>
<td>Light Water</td>
<td>Light Water</td>
<td>300</td>
<td>Most nuclear countries</td>
<td>236</td>
</tr>
<tr>
<td>Boiling Water (BWR)</td>
<td>Light Water</td>
<td>Light Water</td>
<td>300</td>
<td>Most nuclear countries</td>
<td>88</td>
</tr>
<tr>
<td>RBMK</td>
<td>Light Water</td>
<td>Graphite</td>
<td>300</td>
<td>Former USSR*</td>
<td>16</td>
</tr>
<tr>
<td>Pressurized Heavy Water (PHWR)</td>
<td>Heavy Water</td>
<td>Heavy Water</td>
<td>300</td>
<td>Canada, Korea, China, Argentina, India, Pakistan</td>
<td>31</td>
</tr>
<tr>
<td>Gas-Cooled (GCR)</td>
<td>Carbon Dioxide, Helium</td>
<td>Graphite</td>
<td>600</td>
<td>UK, Russia</td>
<td>38</td>
</tr>
<tr>
<td>Liquid Metal-Cooled (LMFBR)</td>
<td>Sodium, Lead, Lead-Bismuth</td>
<td>None</td>
<td>600</td>
<td>France, UK, Japan, Russia; former USSR, China and India</td>
<td>7</td>
</tr>
</tbody>
</table>

*Union of Soviet Socialists Republics
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NUCLEAR POWER STATUS AROUND THE WORLD

Table removed for copyright reasons.
Reactors in operation and under construction, by country - 2001.
RECENT ELECTRIC INDUSTRY TRENDS IN UNITED STATES

- Preparation for Competition
- Power upgrades
- Uncertainty in deregulation pace
- Growth of Combined Cycle Gas Turbine Units
- Merchant plant sector has been growing
- Nuclear Power Plant Set Has Stabilized at 103
  - 2/3 PWR, 1/3 BWR
  - Six units were shut-down
  - No units are being built
  - A few restarts are being considered
- Nuclear Workforce is Old
SOME INTEREST IN NEW NUCLEAR PLANTS

• Nuclear Power Reduces Global Warming, Regional Air Pollution

• DOE/Utility Combined Operating License (COL) Initiative, New Site Licensing
  – Group 1: Constellation, Entergy, Exelon, Southern, EDF International, Westinghouse
  – Group 2: Dominion, GE, Hitachi, Bechtel

• BNFL Participation in South African Pebble-Bed, Gas-Cooled Reactor (formerly Exelon, too)

• PCAST Report (to President) Favorable to Nuclear Projects

• USDOE’s Generation-IV Reactor Program (with Nine Other Countries)

• High Capital Costs Are Still a Problem
GENERATION-IV REACTOR DEVELOPMENT PROGRAM

TEN COUNTRIES PARTICIPATING

• Positive Reactor Products
  – Electricity
  – High Temperature Heat
  – Hydrogen
  – Water
  – Fertilizer

• Concepts
  – Super Critical Water Reactor
  – Very High Temperature (Gas-Cooled) Reactor
  – Sodium-Cooled Fast Breeder Reactor
  – Lead-Bismuth-Cooled Fast Breeder Reactor
  – Gas-Cooled Fast Breeder Reactor
  – Molten Salt Reactor
ENERGY FLOW, 2002 (Quadrillion Btu)

- Coal: 22.55
- Natural Gas: 19.56
- Crude Oil: 12.31
- Nuclear Electric Power: 8.15
- Renewable Energy: 5.90
- NGPL: 2.56

Domestic Production: 70.95
Imports: 29.04
Exports: 3.65
Other: 2.62

Coal: 22.18
Natural Gas: 23.06
Fossil Fuels: 83.49
Consumption: 97.35
Nuclear Electric Power: 8.15
Renewable Energy: 5.90

Residential: 20.94
Commercial: 17.40
Industrial: 32.49
Transportation: 26.52

Notes:
- Includes lease condensate.
- Natural gas plant liquids.
- Conventional hydroelectric power, wood, waste, ethanol blended into motor gasoline, geothermal, solar, and wind.
- Includes -0.09 quadrillion Btu hydroelectric pumped storage.
- Natural gas, coal, coal coke, and electricity.
- Stock changes, losses, gains, miscellaneous blending components, and unaccounted-for supply.
- Crude oil, petroleum products, natural gas, electricity, and coal coke.
- Includes supplemental gaseous fuels.
- Petroleum products, including natural gas plant liquids.
- Includes 0.06 quadrillion Btu of coal coke net imports.
- Includes, in quadrillion Btu, -0.09 hydroelectric pumped storage; -0.17 ethanol blended into motor gasoline, which is accounted for in both fossil fuels and renewable energy but counted only once in total consumption; and 0.08 electricity net imports.
- Primary consumption, electricity retail sales, and electrical system energy losses, which are allocated to the end-use sectors in proportion to each sector’s share of total electricity retail sales. See note at end of Section 2.

Sources: Tables 1.1, 1.2, 1.3, 1.4, and 2.1a.
ELECTRICITY FLOW, 2002 (Quadrillion Btu)

- Coal 20.19
- Fossil Fuels 27.47
- Energy Consumed To Generate Electricity 39.56
- Conversion Losses 25.77
- Gross Generation of Electricity 13.79
- Net Generation of Electricity 13.10
- End Use 12.49
- Retail Sales 11.86
- Transport 0.02
- Commercial 4.12
- Industrial 3.39
- Residential 4.33
- Plant Use 0.69
- T & D Losses 1.24

Other Gases 0.13
Natural Gas 6.19
Nuclear Electric Power 8.15
Renewable Energy 3.98
Other 0.05
Hydroelectric Pumped Storage 0.09
Unaccounted for 0.56
Electricity Imports 0.12
Electricity Exports 0.05
Direct Use 0.63

Notes:
- Blast furnace gas, propane gas, and other manufactured waste gases derived from fossil fuels.
- Batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.
- Pumped storage facility production minus energy used for pumping.
- Approximately two-thirds of all energy used to generate electricity. See note at end of Section 2.
- Data collection frame differences and non-sampling error.
- Electric energy used in the operation of power plants, estimated as 5 percent of gross generation. See note at end of Section 2.
- Transmission and distribution losses, estimated as 9 percent of gross generation. See note at end of Section 2.
- Commercial retail sales plus approximately 95 percent of “Other” retail sales from Table 8.5.
- Approximately 5 percent of “Other” retail sales from Table 8.5.
- Commercial and industrial facility use of onsite net electricity generation; and electricity sales among adjacent or co-located facilities for which revenue information is not available.

Sources: Tables 2.2a, 8.1, 8.5, and A6.

Energy Information Administration / Annual Energy Review 2002
ENERGY PRODUCTION BY SOURCE

(s)=Less than 0.5 quadrillion Btu.
Note: Because vertical scales differ, graphs should not be compared.
Source: Table 1.2.
NUCLEAR GENERATING UNITS

Status of All Ordered Units, 1953-2002

- Operable: 104
- Pending: 3
- Cancelled: 124

Total Units Ordered: 259

Operable Units,¹ 1957-2002

- Peak: 112 Units in 1990
- 104 Units in 2002

Orders, Permits, and Operable Units, 1953-2002

- Cumulative Units Ordered
- Cumulative Construction
- Permits Issued
- Operable Units

Cancellations and Shutdowns, 1953-2002

- Cumulative Cancellations
- Cumulative Shutdowns

¹ Issuance by a regulatory authority of full-power operating license, or equivalent permission to operate.
² Ordered but not completed or cancelled.
³ Ceased operation permanently.
⁴ Placement of an order by a utility for a nuclear steam supply system.
⁵ Issuance by a regulatory authority of a permit, or equivalent permission, to begin construction.
⁶ Cancellation of ordered units.

Note: Data are at end of year.
Source: Table 5.1.

Energy Information Administration / Annual Energy Review 2002
HISTORICAL AND PROJECTED US NUCLEAR ELECTRIC GENERATION CAPACITY, 1960-2055
NUCLEAR GENERATING UNITS

Operable Units By Site, 2000

Energy Information Administration/Annual Energy Review, 2000
INTERNATIONAL TRENDS

• Deregulation originated in the United Kingdom, went well until recently; now British Energy is near bankruptcy

• Deregulation is also being tried in United States, Canada, Chile, Japan, South Korea, Australia, and European Community

• Consolidation among nuclear equipment vendors is occurring: Framatome ANP, British Nuclear Fuels Ltd, General Electric/Toshiba, Hitachi, Mitsubishi Heavy Industries
REGIONAL FACTORS

EUROPE

- Electricite de France is a big exporter and owner, preparing for competition
- Nuclear power shutdowns have been voted in Sweden, Germany and Belgium
- Fifth Finnish nuclear unit order is proceeding

AFRICA

- South Africa developing the pebble bed modular reactor (PBMR)
REGIONAL FACTORS, continued

ASIA

• China is accelerating its nuclear power program as an alternative to coal-based electricity, two units in pipeline now

• Japan has three units in pipeline; cover-up scandals settling down; all 15 units of TEPCO were off-line during March ’03

• South Korea had privatized KEPCO, is planning a new series of LWRs, has six units in pipeline

• Taiwan is completing two BWRs (Units 7 & 8); nothing is planned beyond them
WORLD PRIMARY ENERGY PRODUCTION BY SOURCE

Total and Crude Oil and NGPL\(^1\), 1970-2001

By Source, 2001

By Source, 1970-2001

Notes: • Crude oil includes lease condensate. • Because vertical scales differ, graphs should not be compared.

Source: Table 11.1.

\(^1\)Natural gas plant liquids
\(^2\)Net electricity generation from wood, waste, solar, and wind. Data for the United States also include other renewable energy.
WORLD CARBON DIOXIDE EMISSIONS FROM ENERGY CONSUMPTION

Leading Countries, 2001

Notes: Data include emissions from motor vehicles and fossil fuel
                 consumption. Therefore, values are not directly
                 comparable. Table A11.19.
PLAUSIBLE TRENDS IN REACTOR TECHNOLOGY EVOLUTION

CURRENT/SHORT TERM

Light Water Reactors (LWRs)
- Pressurized Water Reactor (PWR)
- Boiling Water Reactor (BWR)
- Pressurized Heavy Water Reactor (CANDU)

INTERMEDIATE TERM (>20 years)

Brayton Cycle Gas (He) Cooled Reactor (GCR-GT)

LONG TERM (>50 years)

Fast Breeder ($^{238}\text{U}\otimes^{239}\text{Pu}$-based)
Thermal Breeder ($^{232}\text{Th}\otimes^{233}\text{U}$-based)
MHTGR SIDE-BY-SIDE ARRANGEMENT WITH PRISMATIC FUEL

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FACTORS LIKELY TO AFFECT FUTURE USE OF NUCLEAR POWER

Operational Safety Record
Utility, Critical Elite, Public, Investor Attitudes
End of Cold War
Degree of Nuclear Weapons Proliferation
Nuclear Waste Disposal Success
Global Warming and Air Pollution Worries