Nuclear Power After Fukushima
Where is it Heading?

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International Energy Workshop
Cape Town, June 2012
Nuclear Power: Years of Boredom Interrupted by Moments of Sheer Terror?

Low estimate based on the age of reactors operating today, IAEA Power Reactor Information System (actual value for 2010 closer to 14,000 reactor years)

Accidents with local or wider consequences
Levels 4 and higher on International Nuclear Event Scale (INES)

Incidents (selected)
Levels 3 and lower on INES

Several additional accidents occurred prior to 1960 including the Windscale (1957), Mayak (1957), and Simi Valley (1959) accidents
Watershed Moment or Storm in a Teacup?

International Responses To Fukushima
In Germany, the Fukushima Accidents Overnight Consolidated Support for Nuclear Phaseout

86% support nuclear phaseout by 2020 (Polling data from April 4–5, 2011)

Top: www.presseportal.de/pm/6694/2022635/ard_das_erste
Left: Spiegel Cover from March 14, 2011: The End of the Atomic Era
Germany’s Electricity Imports/Exports

The Impact of Post-Fukushima Shutdowns is Visible but not Dramatic

Germany’s GHG Emissions Have Not Spiked Despite the Shutdown of 7* Reactors in March 2011

*One additional reactor was already shut down at the time

See also European Central Data Repository, cdr.eionet.europa.eu/de/eu/ghgmm/envtw7blw
The International Response to the Fukushima Accidents Has Been Very Uneven

<table>
<thead>
<tr>
<th>Country</th>
<th>Action</th>
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<tbody>
<tr>
<td>Germany</td>
<td>Consolidating a national consensus on phaseout of nuclear power</td>
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<td>• Immediate shutdown of eight oldest (out of a fleet of seventeen) reactors</td>
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<td>• Complete phaseout by 2022</td>
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<td>Japan</td>
<td>Fundamental review of energy policy underway</td>
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<td></td>
<td>• As of May/June 2012, all 50 reactors shut down; several units are unlikely to come back online</td>
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<td>• 4 energy mix scenarios; public support for reduced role of nuclear power in the future</td>
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<td>France</td>
<td>New government considers adjustments to French energy policy</td>
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<td>• Planned reduction of nuclear electricity generation from almost 80% down to 50% by 2025−2030</td>
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<td>• Major life-extension program underway: EUR 40 billion plus EUR 10 billion post Fukushima</td>
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The International Response to the Fukushima Accidents Has Been Very Uneven

Reconsidering a new or more important role of nuclear power
- Mostly relevant for non-committed “newcomer” countries
- Also includes countries with existing small programs (Belgium, Switzerland, the Netherlands, …)

Ambitious expansion plans largely unaffected
- Safety review of all current plants; possible new licensing requirements for future plants
- Target for 2020: add 35–45 GW to existing 12 GW (Share of nuclear electricity in 2011: 1.85%)

Continued commitment to nuclear power
but only few new construction projects moving forward despite government support
United States: The Market is Deciding

Federal Loan Guarantees
as part of the Energy Policy Act of 2005, up to $18.5 billion
Obama Administration has sought to increase amount to $54.5 billion

Most proposed construction projects have stalled
some before and some after the Fukushima Accidents

Vogtle-3 and -4 Project (Waynesboro, GA) moving forward
2 x Westinghouse AP-1000, 2200 MWe, expected for 2016 and 2017
Combined Construction and Operating License issued in February 2012
$14 billion investment; $8.3 billion in Federal loan guarantees

“Let me state unequivocally that I’ve never met a nuclear plant I didn’t like;
Having said that, let me also state unequivocally that new ones don’t make any sense right now.”
John Rowe, Former CEO Exelon, March 29, 2012
Looking Forward
Nuclear Power Reactors in the World, 2012

436 operational reactors (8 fewer than 12 months ago) in 31 countries provide about 13% of global electricity.
The Existing Fleet of Power Reactors is Aging
(20-year life-extensions have already been granted for most U.S. reactors)

- **Operating, nearing 40-year life (75)**
- **Operating, first criticality after 1975 (361)**
- **Under construction (62)**
- **Destroyed in accidents (6)**
- **Shutdown in response to accidents (8)**

As of May 2012, all reactors shut down
Restart of 2 reactors has been authorized in June 2012

*Minimum number*

**Source:** IAEA Power Reactor Information System
**Last revision:** May 2012
Construction Starts By Year

Information retrieved: June 19, 2012
Many Energy Scenarios (Still) Envision an Early Large-scale Expansion of Nuclear Power

Many Energy Scenarios (Still) Envision an Early Large-scale Expansion of Nuclear Power

![Bar chart showing new construction in 5-year periods with GCAM 450 ppm Scenario, 50-year average life, and 60-year average life. The chart includes years from 2011-2015 to 2056-2060 with values ranging from 0 to 250 GW. The equivalent historic maximum is shown as 32 GW added in 1984.](chart.png)
Many Energy Scenarios (Still) Envision an Early Large-scale Expansion of Nuclear Power

Global nuclear electricity under GCAM 450 ppm Scenario: 1910 GWe in 2060 (23% of total) and 5190 GWe in 2095 (34% of total)
Global Uranium Enrichment Capacities, 2012

(14 operational plants in 10 countries, not including two military plants)

Legend:
- More than 10 GW installed today
- Less than 10 GW installed today
- Countries that have expressed interest in nuclear power

Total SWU-production in country/region

10,000
20,000
26,200
1,500
120
2,000

Countries that have expressed interest in nuclear power include:
- Brazil
- Canada
- China
- France
- Germany
- India
- Japan
- Korea
- Russia
- Ukraine
- United States
- United Kingdom
Global Uranium Enrichment Capacities, 2060
Based on the requirements for GCAM 450 ppm Scenario in 14 World Regions

Note: 120 tSWU/yr (●) can provide
the low-enriched uranium needed for one gigawatt-scale reactor
(or can be used to make HEU for 25–50 weapons per year)
Are New Technologies on the Horizon?

The Case of Small Modular Reactors
Could Small Nuclear Reactors Play a Role?
Several designs are based on standard light-water reactor technology

Babcock & Wilcox mPower Concept
- Light-water cooled
- 125-750 MWe
- Underground construction
- 60-year spent fuel storage onsite
- Quasi-standard LWR fuel

Source: www.babcock.com/products/modular_nuclear/
Why Consider Small Modular Reactors?

- **Substantially lower investment risks**
  $500 million vs $5 billion projects; combined with shorter construction times

- **Better suited for electricity markets with low growth rates**
  Modules can be added to existing plants “on demand”
SMRs Are Being Considered As a Replacement for Early-Generation Coal Plants

(U.S. example: about 560 coal plants with 1365 generators, ca. 300 GWe)

Source: Peter Lyons, Presentation for SEAB SMR Subcommittee, March 9, 2012
Why Consider Small Modular Reactors?

- **Substantially lower investment risks**
  $1\text{ billion vs }$10\text{ billion projects}; combined with shorter construction times

- **Better suited for electricity markets with low growth rates**
  Modules can be added to existing facilities “on demand”

- **Promise of enhanced safety and security**
  Almost all designs envision underground or other nonconventional siting modes

- **Potential nonproliferation benefits**
  Long-lived cores

In January 2012, DOE announced a 5-year $452 million cost sharing program to support engineering, design certification, and licensing for up to two first-of-a-kind SMR designs

[www.grants.gov/search/search.do?mode=VIEW&oppId=138813](http://www.grants.gov/search/search.do?mode=VIEW&oppId=138813)
Proposed New Deployment Options for SMRs
underground, underwater, on barges

FlexBlue
proposed by DCNS (formerly Direction des Constructions Navales, DCN) jointly with Areva, CEA, and EDF
http://en.dcnsgroup.com/energie/civil-nuclear-engineering/flexblue/

Floating Nuclear Power Plant
proposed by Rosatom
Akademik Lomonosov (2 x 32 MWe) under construction
Some Advanced Designs Rely on Major Departures from Established Technologies and Approaches

EM²: “Nuclear Waste to Energy”
www.ga.com/energy/em2/

Traveling Wave Reactor
www.terrapower.com
Some Preliminary Observations

about the Potential of Small Modular Reactors

**Multitude of Proposed Reactor Designs**

Design choices will determine viability of systems for large-scale deployment

Resource utilization and proliferation risks may or may not be significantly different

(relative to gigawatt-scale reactors in use today)

**Economics of SMR are highly uncertain and typically higher for more mature projects**

$4000–5000/kWe for Western vendors; only cost estimates for Chinese designs are lower

Ongoing “negotiations” between regulatory agencies and SMR applicants

Staffing (control room and security), emergency planning, fees, insurance and liability

Highly dependent on learning rates (LEAD/FOAK vs NOAK)

Some studies assume a rate on the order of 10%; requires about 50 modules for break-even
Where Is Nuclear Power Heading?
Some Concluding Observations

Many countries remain committed to nuclear power but deployment and role of nuclear power is likely to be more uneven. Germany’s phaseout will be a “game changer”.

Small Modular Reactors

SMR attract significant attention; many innovative features; some prototypes will be built.

Small may be beautiful ... but it is small

Even under most optimistic assumptions, little generating capacity based on SMR technologies could be deployed by 2030.

An early large-scale global nuclear expansion has become very unlikely.

New thinking is needed about the potential (smaller) role of nuclear power in energy portfolios.