Nuclear Power After Fukushima

Where is it Heading?

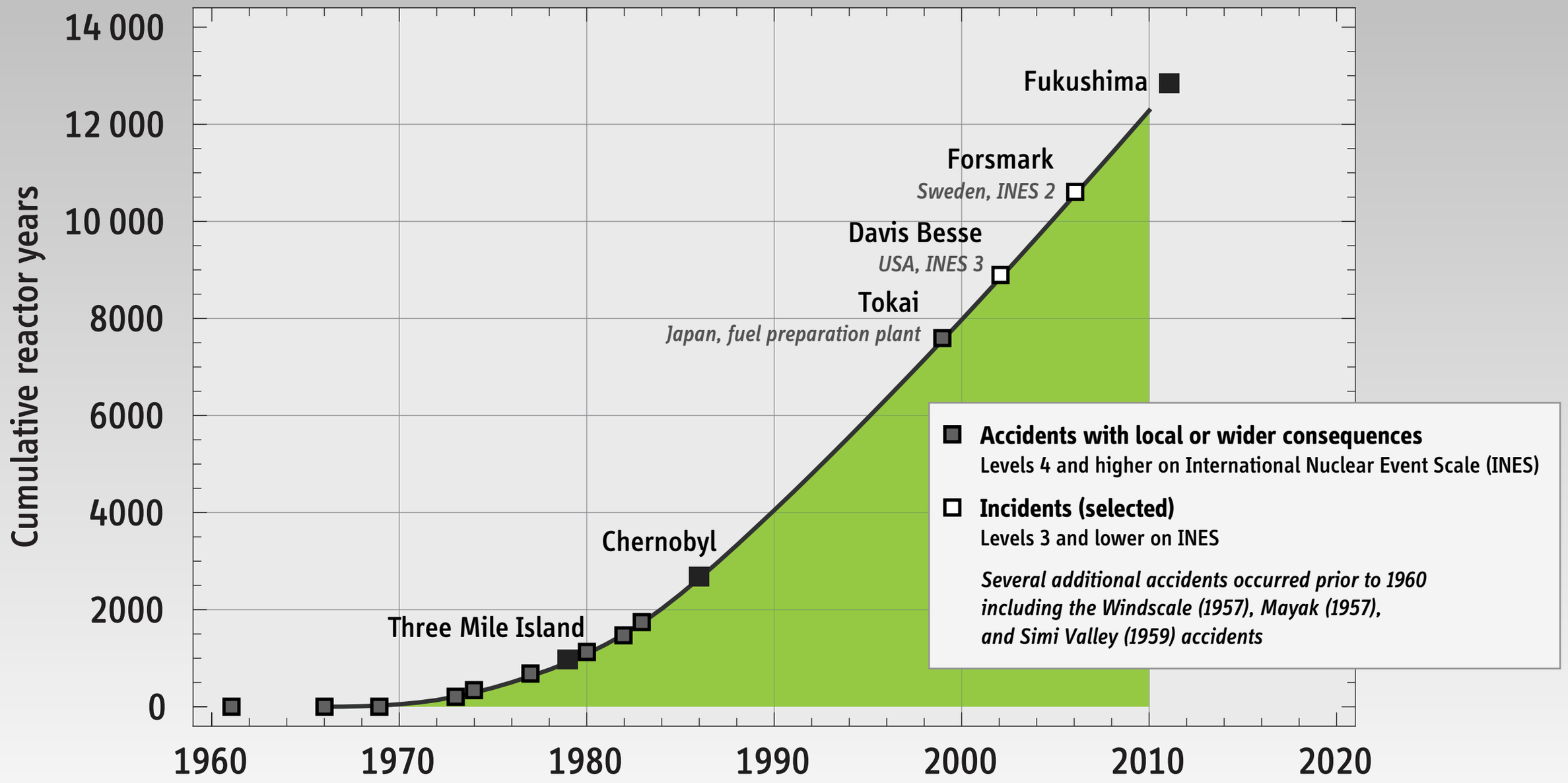
Alexander Glaser

Department of Mechanical and Aerospace Engineering
and Woodrow Wilson School of Public and International Affairs
Princeton University

International Energy Workshop
Cape Town, June 2012

Revision 5

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)

Fukushima-Daiichi Plant

Source: TEPCO, undated

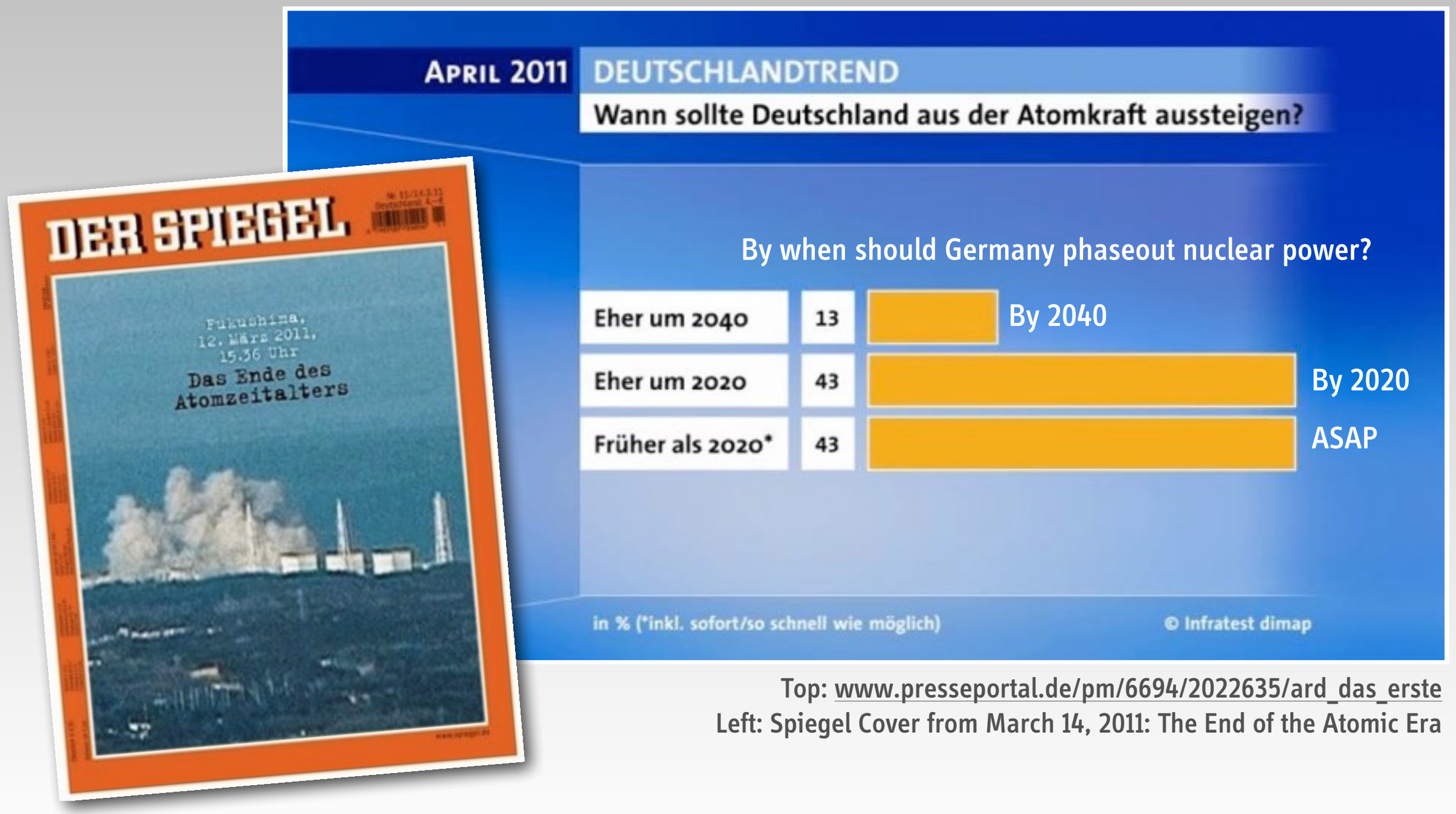
March 14, 2011 - DigitalGlobe

Watershed Moment or Storm in a Teacup?

International Responses To Fukushima

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

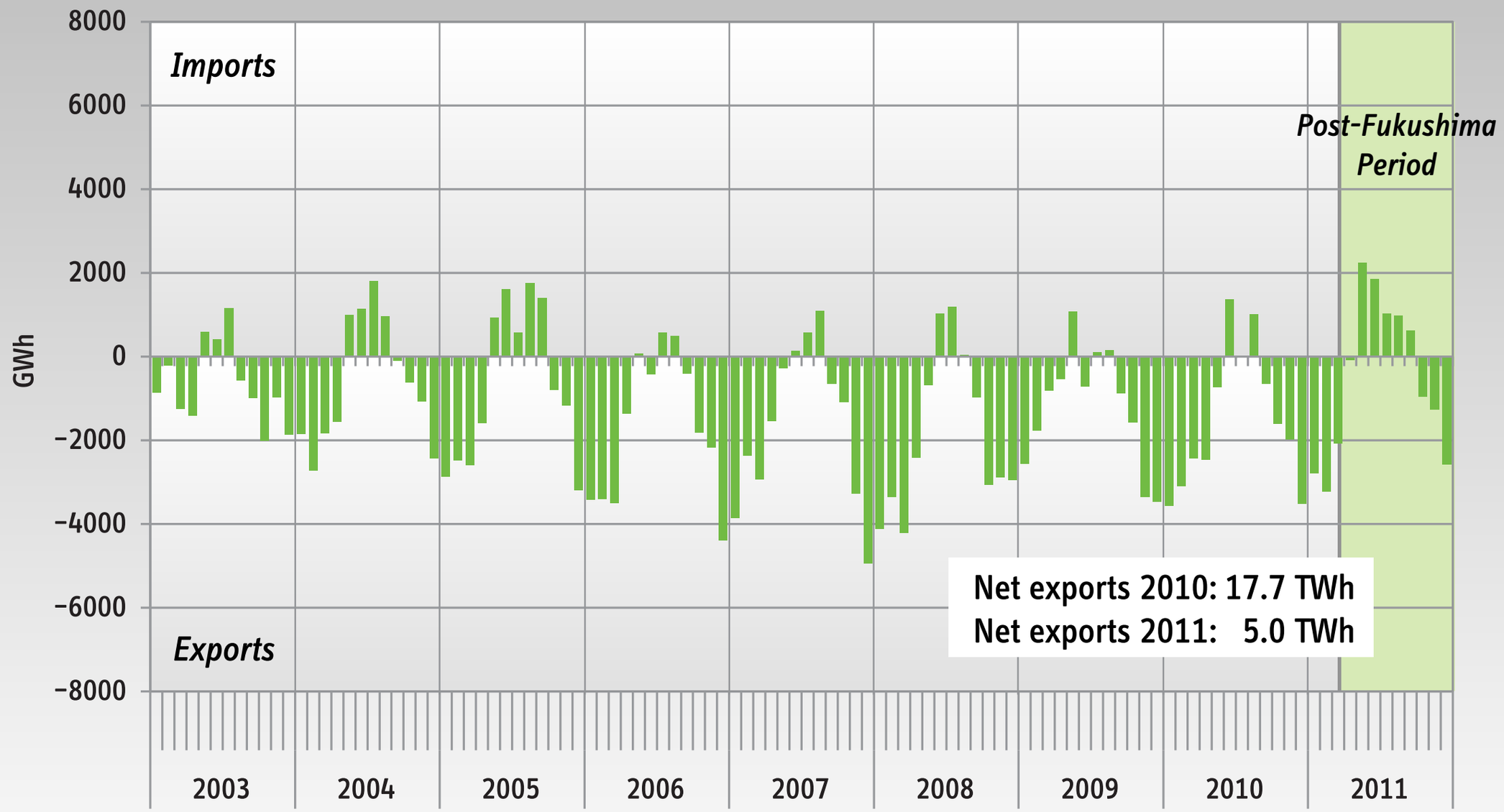
86% support nuclear phaseout by 2020 (Polling data from April 4–5, 2011)



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

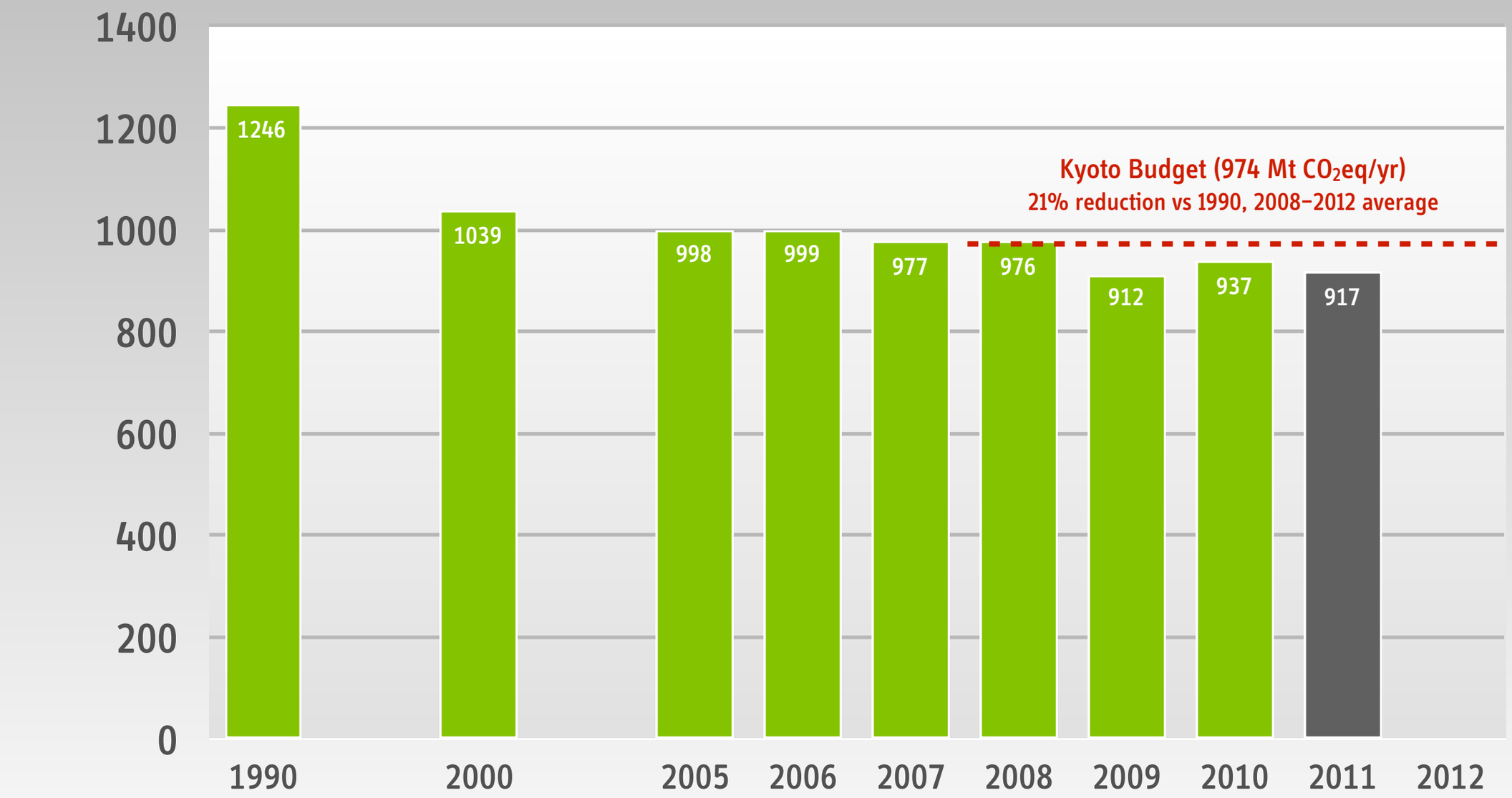
The Impact of Post-Fukushima Shutdowns is Visible but not Dramatic



Charlotte Loreck, *Atomausstieg in Deutschland*, Institute of Applied Technology, Darmstadt, March 2012

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



"Weniger Treibhausgase mit weniger Atomenergie," Press Release, 17/2012, Umweltbundesamt, April 12, 2012
See also European Central Data Reposoitory, cdr.eionet.europa.eu/de/eu/ghgmm/envtw7blw

The International Response to the Fukushima Accidents Has Been Very Uneven

Germany

Consolidating a national consensus on phaseout of nuclear power

- Immediate shutdown of eight oldest (out of a fleet of seventeen) reactors
- Complete phaseout by 2022

Japan

Fundamental review of energy policy underway

- As of May/June 2012, all 50 reactors shut down; several units are unlikely to come back online
- 4 energy mix scenarios; public support for reduced role of nuclear power in the future

France

New government considers adjustments to French energy policy

- Planned reduction of nuclear electricity generation from almost 80% down to 50% by 2025–2030
- Major life-extension program underway: EUR 40 billion plus EUR 10 billion post Fukushima

The International Response to the Fukushima Accidents Has Been Very Uneven

several

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, ...)

China

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%)

USA

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."

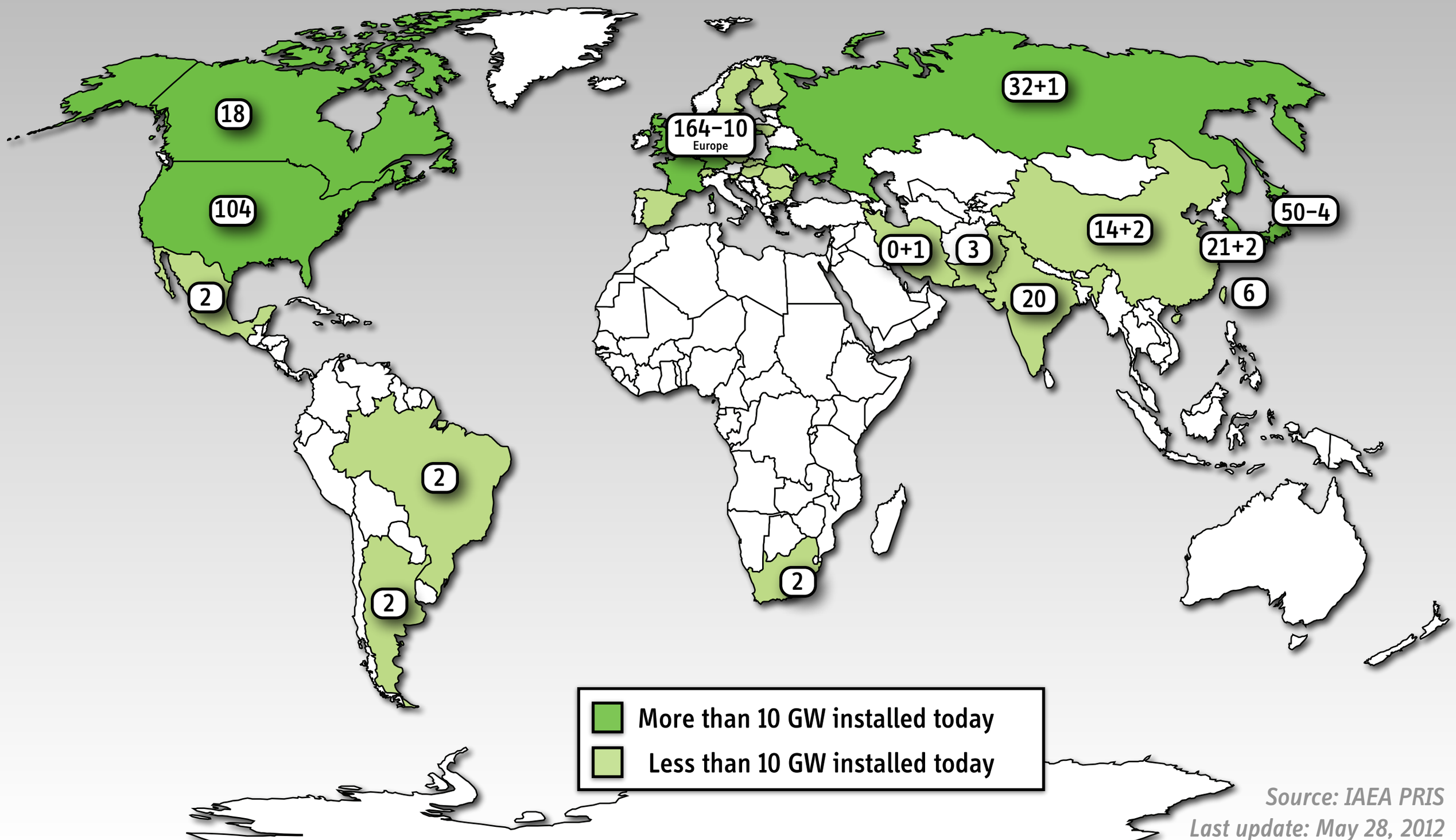
John Rowe, Former CEO Exelon, March 29, 2012

quoted in www.forbes.com/sites/jeffmcmahon/2012/03/29/exelons-nuclear-guy-no-new-nukes

Looking Forward

Nuclear Power Reactors in the World, 2012

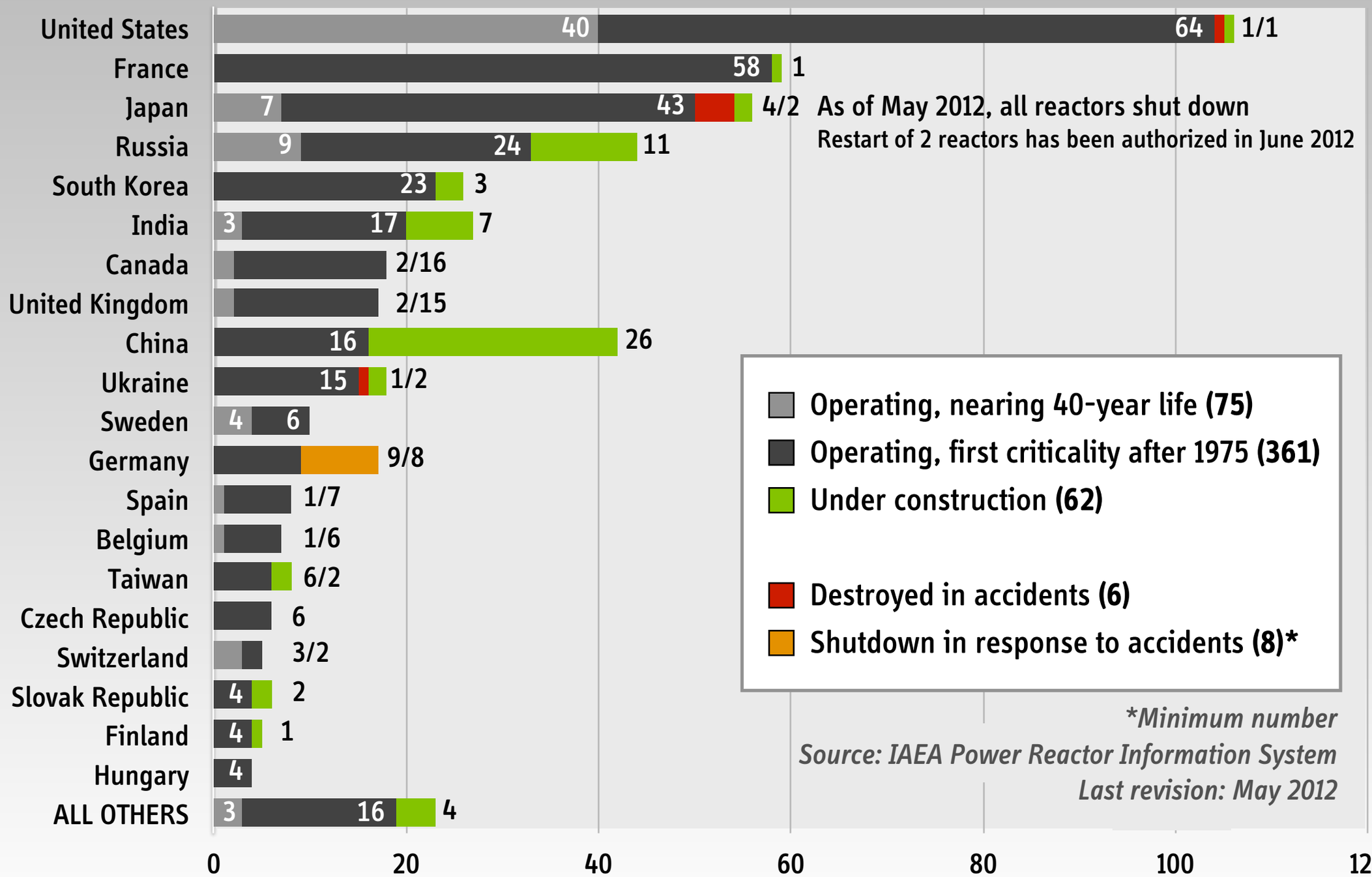
436 operational reactors (8 fewer than 12 months ago) in 31 countries provide about 13% of global electricity



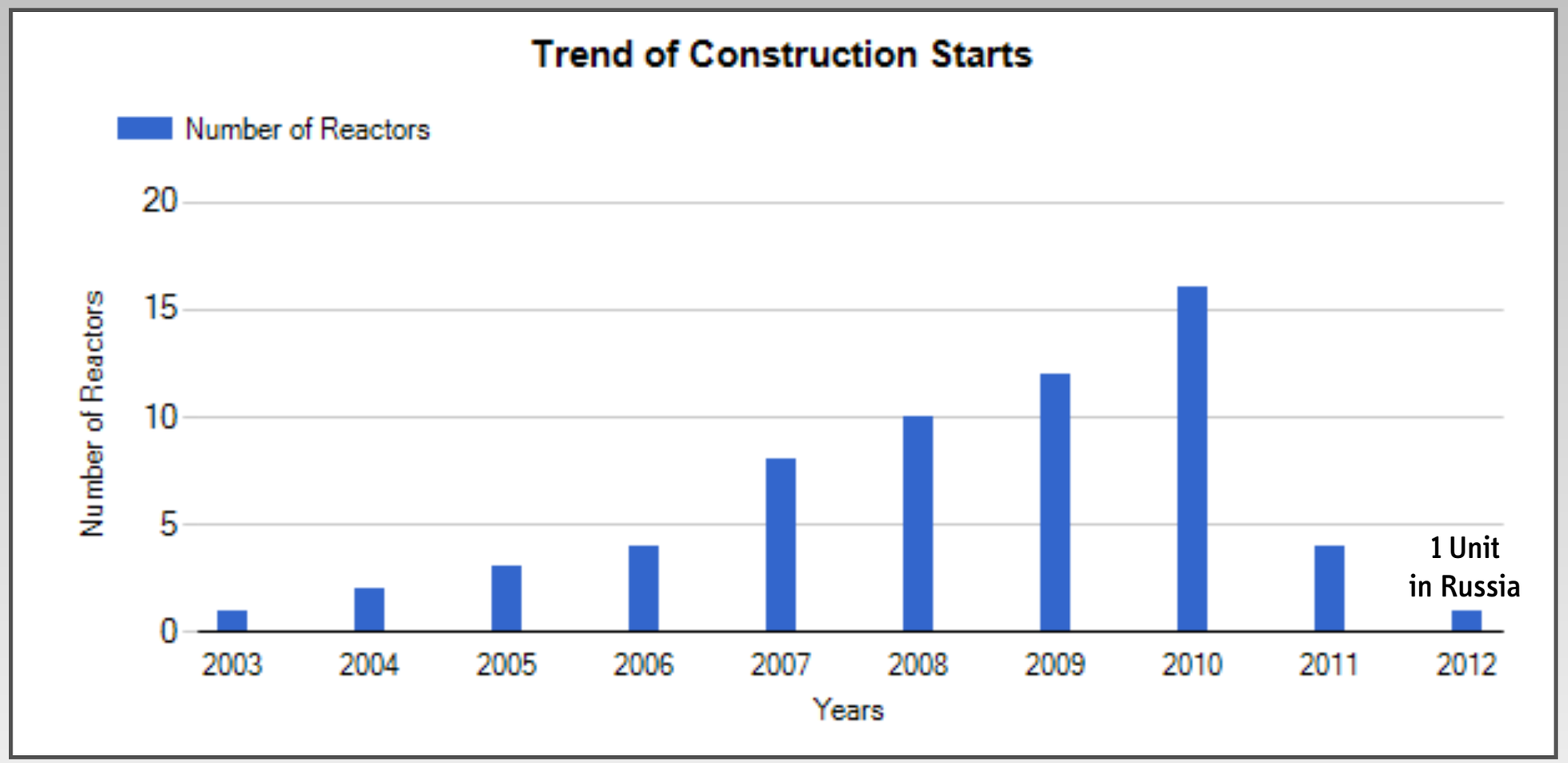
Source: IAEA PRIS
Last update: May 28, 2012

The Existing Fleet of Power Reactors is Aging

(20-year life-extensions have already been granted for most U.S. reactors)

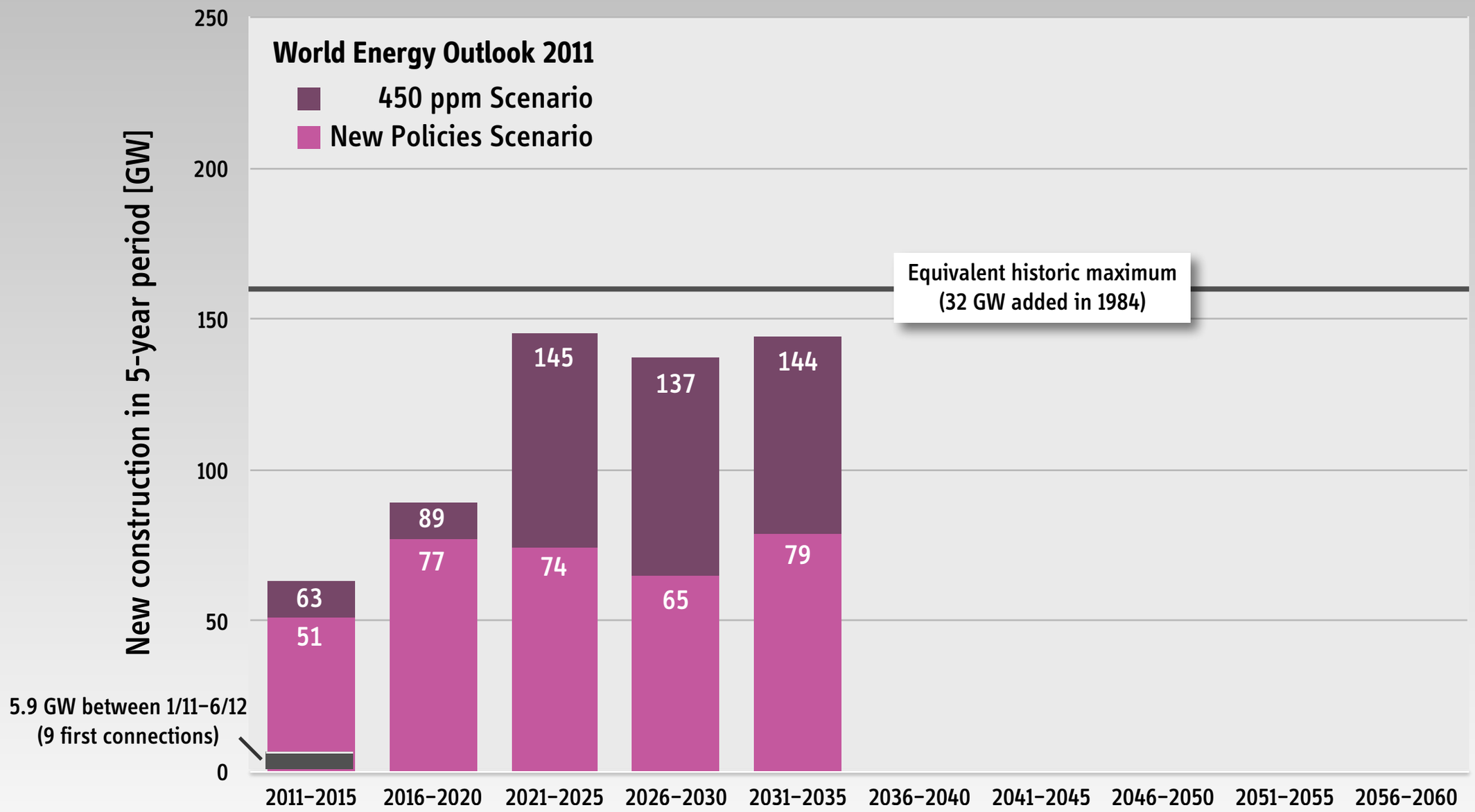


Construction Starts By Year



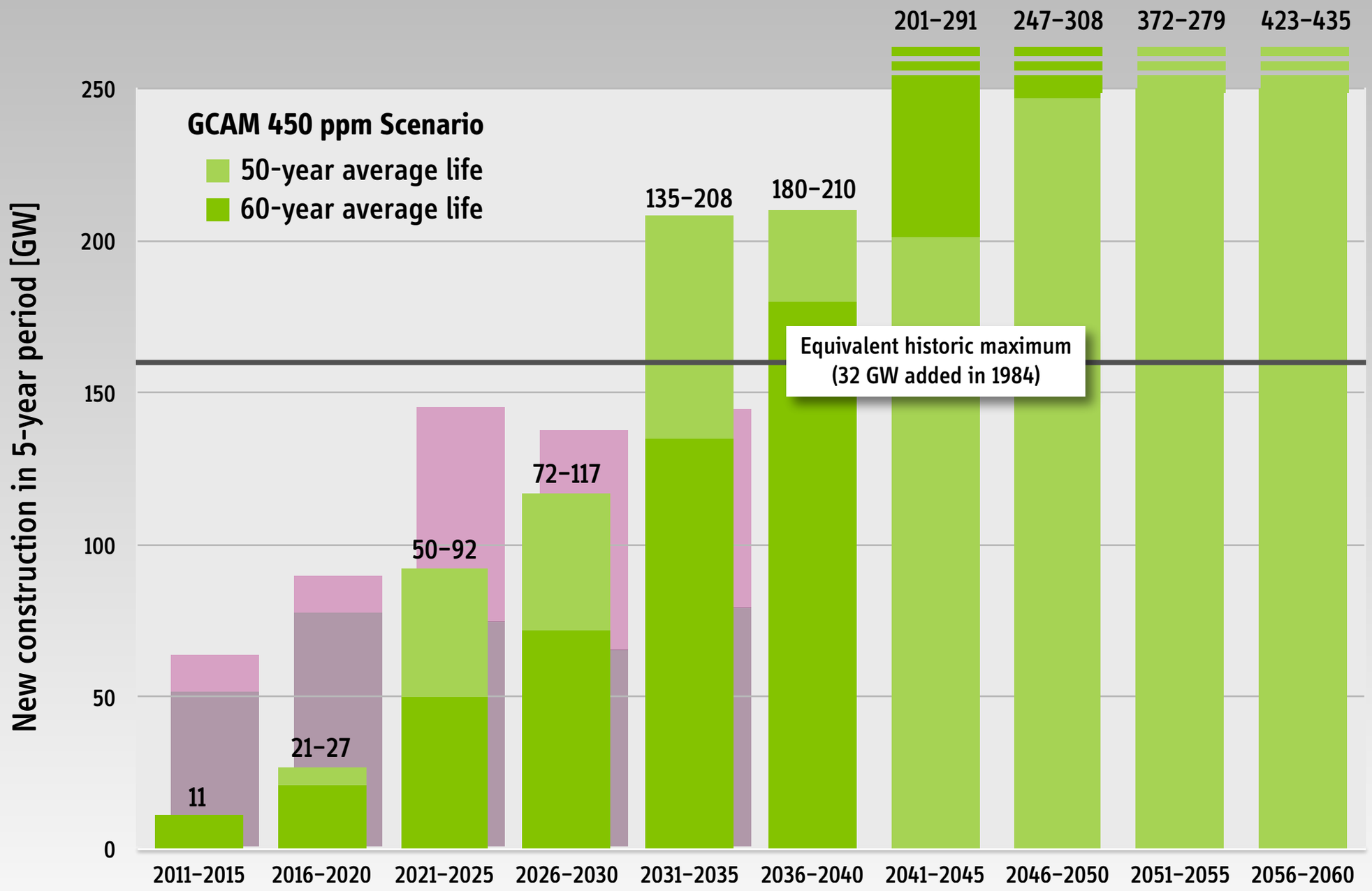
Source: Power Reactor Information System (PRIS), International Atomic Energy Agency, http://pris.iaea.org/public/
Information retrieved: June 19, 2012

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

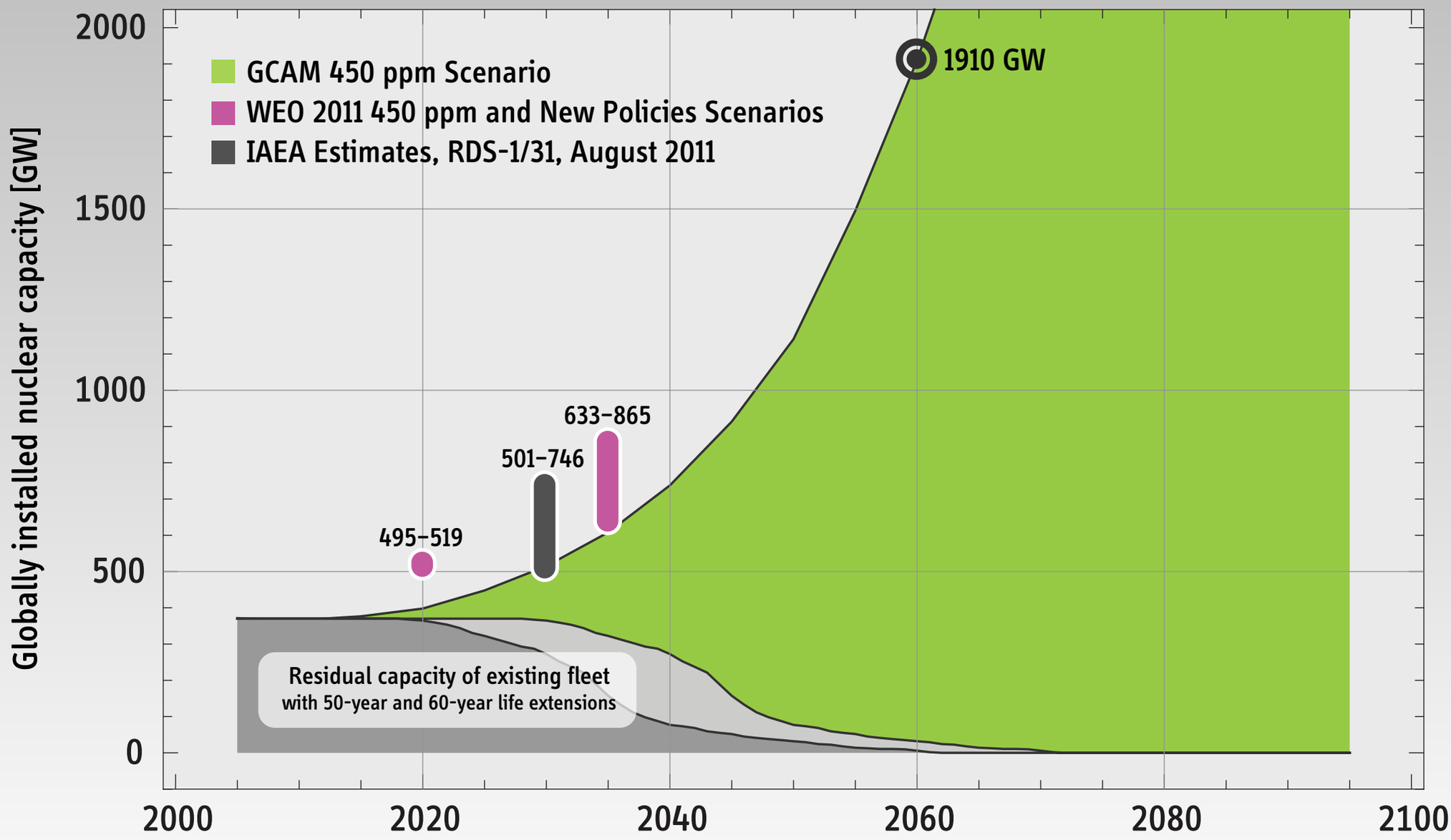


Data based on Figure 5.7 and Annex A, *World Energy Outlook 2011*, International Energy Agency, OECD/IEA, Paris, 2011

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



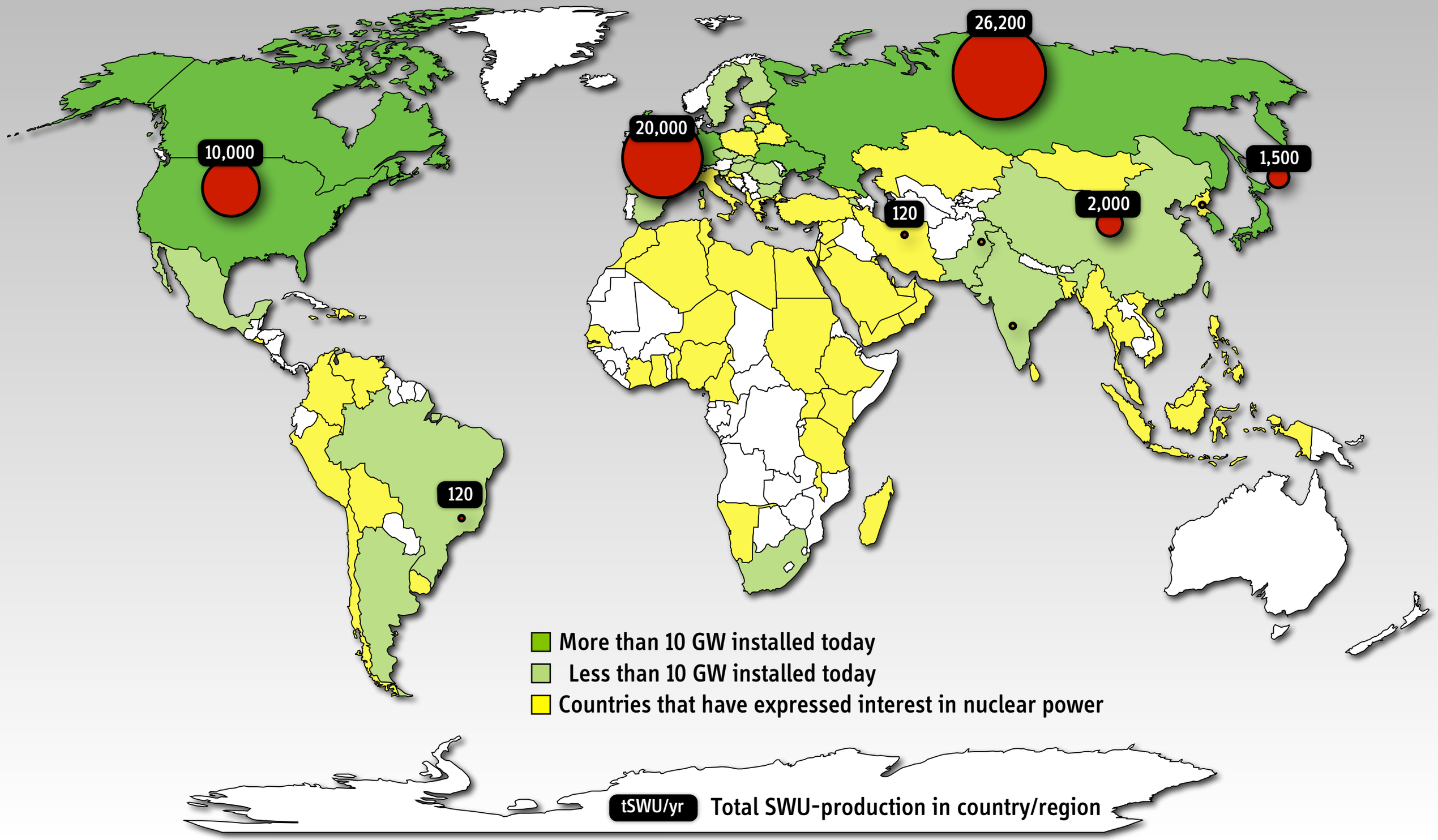
Many Energy Scenarios (Still) Envision an Early Large-scale Expansion of Nuclear Power



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

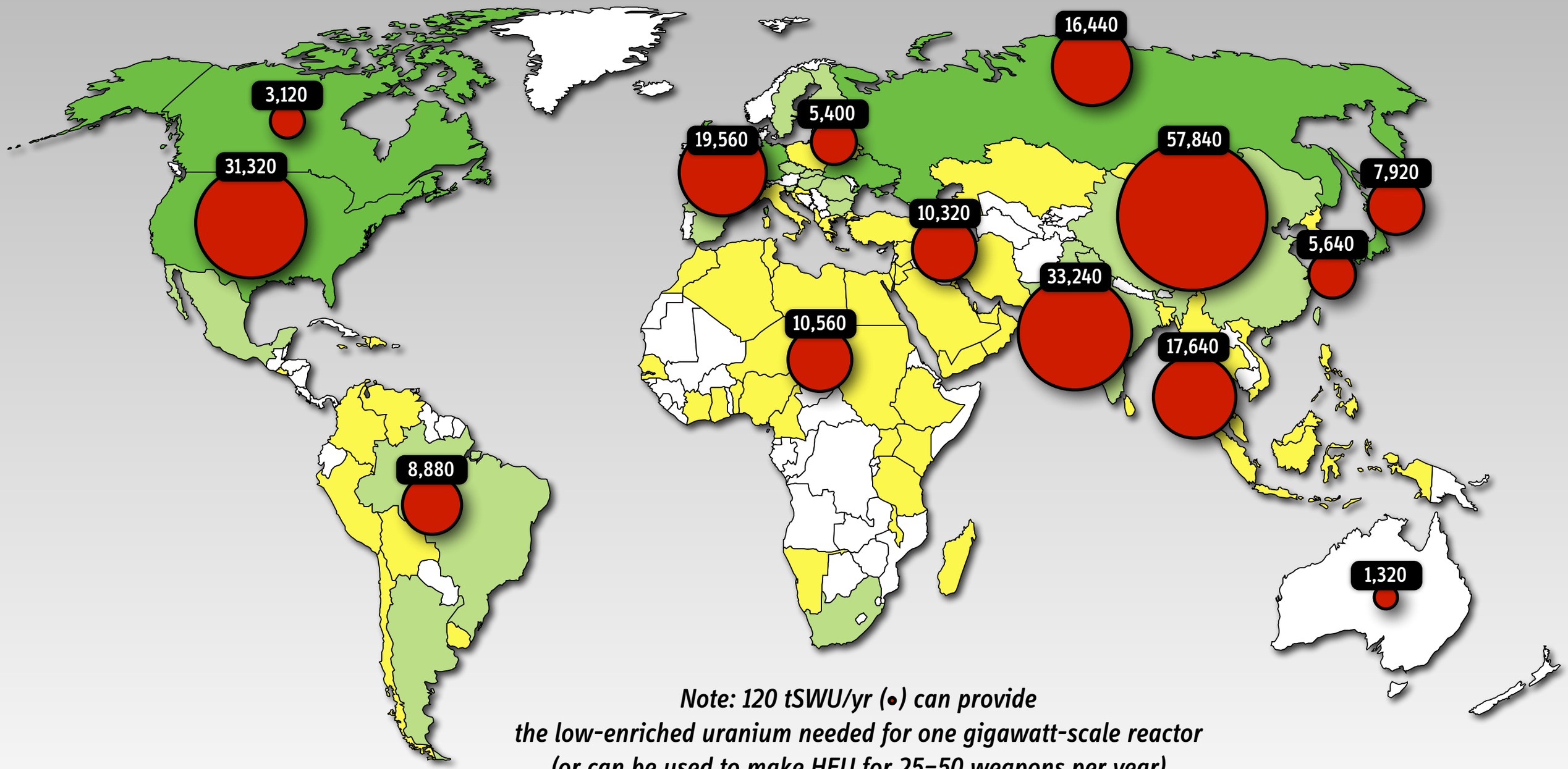
Global Uranium Enrichment Capacities, 2012

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



Global Uranium Enrichment Capacities, 2060

Based on the requirements for GCAM 450 ppm Scenario in 14 World Regions



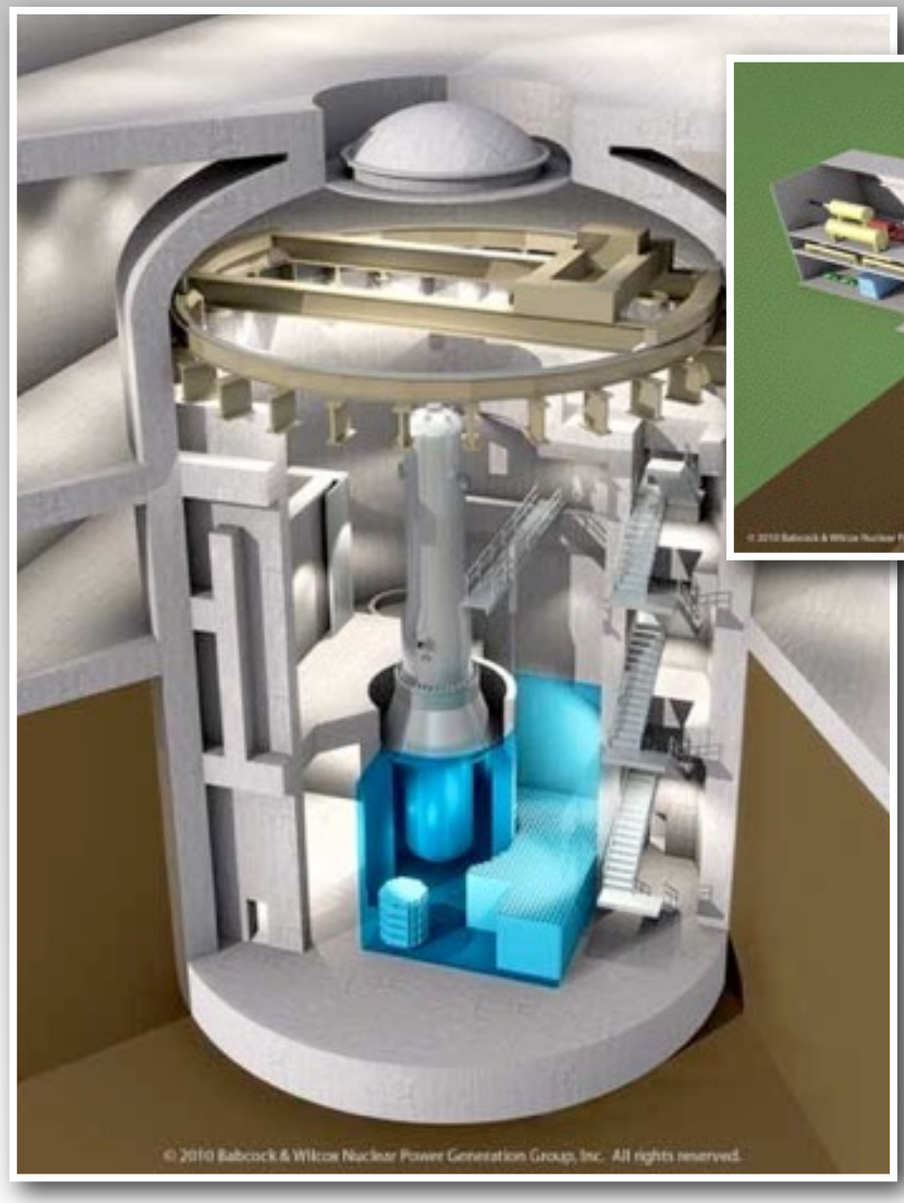
Note: 120 tSWU/yr (•) can provide
the low-enriched uranium needed for one gigawatt-scale reactor
(or can be used to make HEU for 25–50 weapons per year)

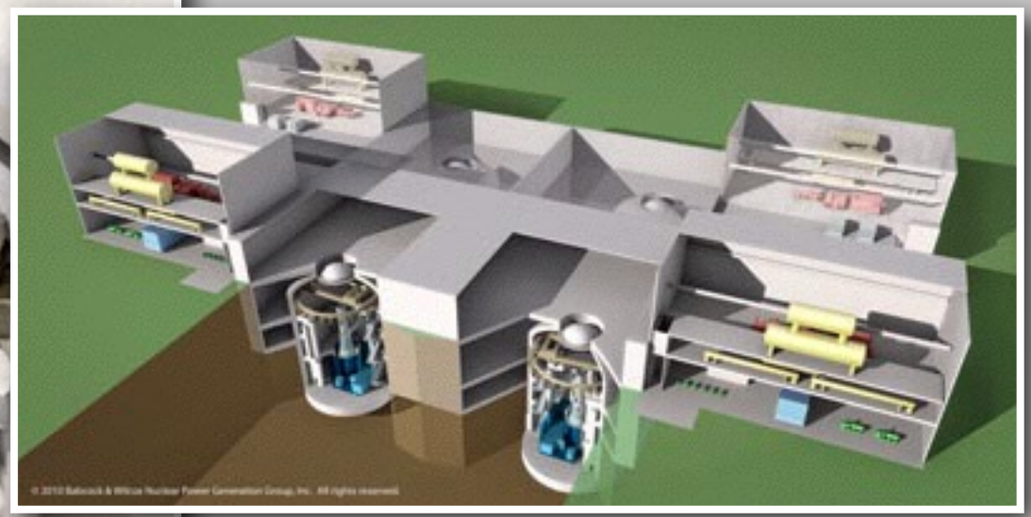
Are New Technologies on the Horizon?

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/

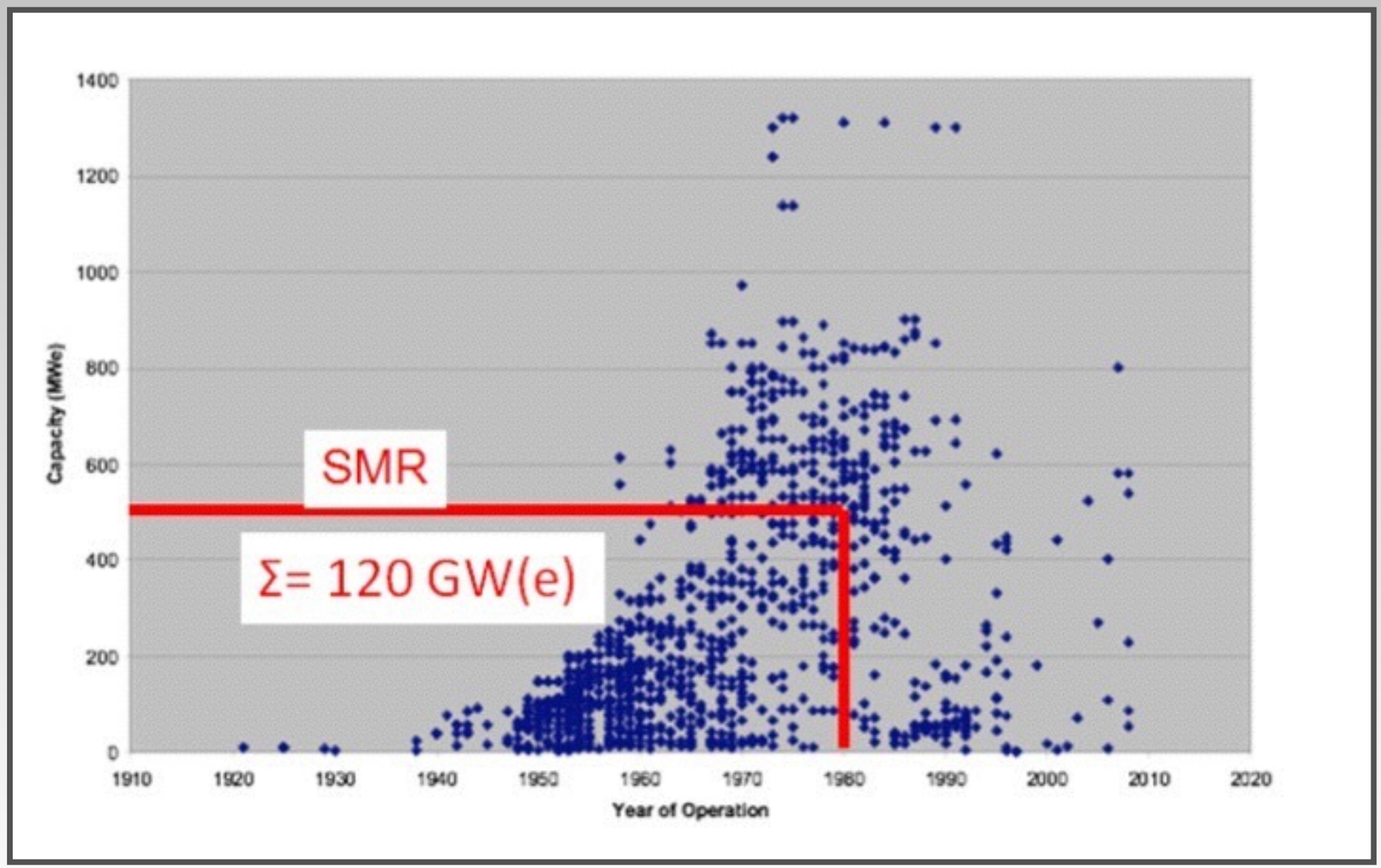
Why Consider Small Modular Reactors?

- **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 billion vs $10 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

Proposed New Deployment Options for SMRs

underground, underwater, on barges

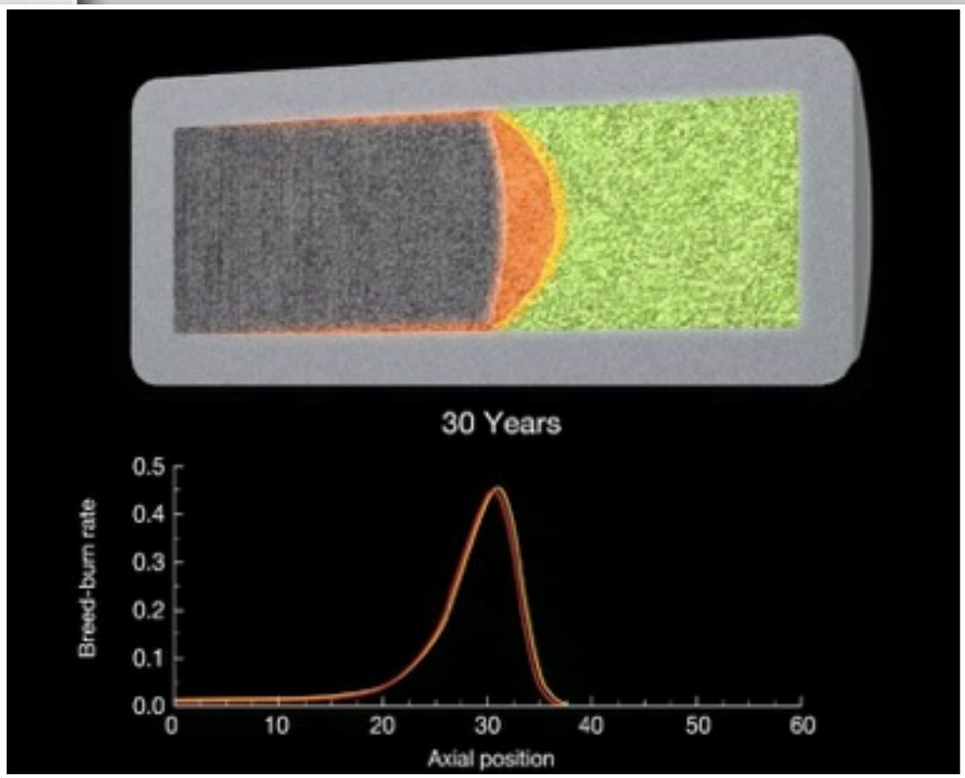
FlexBlue
proposed by DCNS (formerly *Direction des Constructions Navales*, DCN) jointly with Areva, CEA, and EDF
http://en.dcnsgroup.com/energie/civil-nuclear-engineering/flexblue/

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